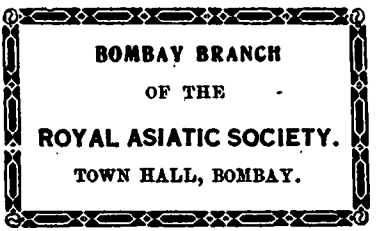
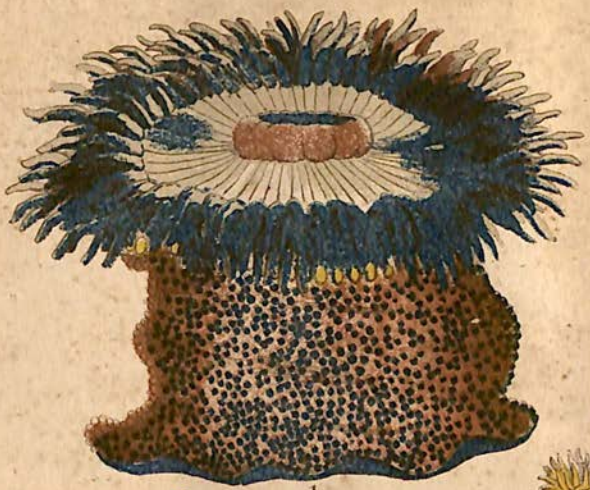
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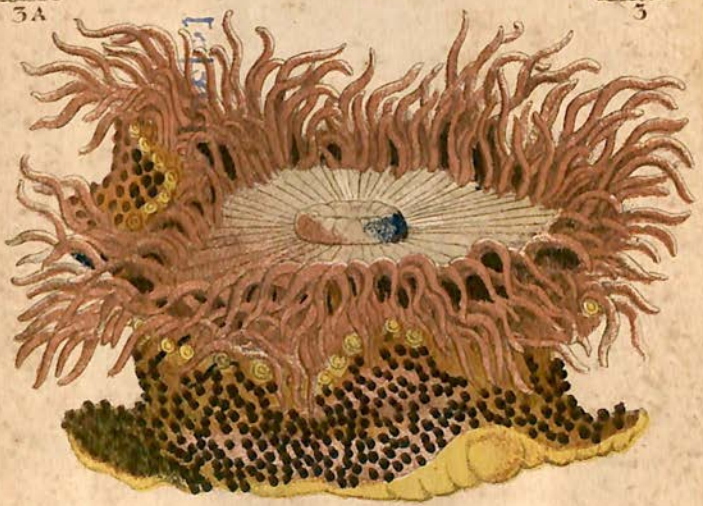
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CORALS

AND

CORAL ISLANDS.

38626

BY

JAMES D. DANA, LL.D.,

Professor of Geology and Mineralogy in Yale College; Author of Reports, in connection with the Wilkes U.S. Exploring Expedition, on Geology, Zoöphytes, and Crustacea of a System of Mineralogy; Manual of Geology, etc.

"We wandered where the dreamy palm
Murmured above the sleeping wave;
And through the waters clear and calm,
Looked down into the coral cave."
J. C. P., *U.S.N Expl. Expd.*

London:
SAMPSON LOW, MARSTON, LOW AND SEARLE,
CROWN BUILDINGS, 188, FLEET STREET.
1875.

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PREFACE

TO THE ENGLISH EDITION.

In presenting this volume to English readers, the prominent part which the science of Britain has borne in the development of the subjects discussed comes naturally to mind. The remarkable works and memoirs of Ellis, from 1754 to 1786, which forced Linnæus and Pallas ultimately to admit that corals belong to the animal kingdom, gave the earliest great impulse to the study of this branch of Zoölogy. On the other hand, Darwin's admirable investigations first made known the true nature and theory of coral reefs and islands. The publications of Ellis were constantly by my side in the preparation of my "Report on Zoöphytes;" and the theory of Darwin—as I have stated in my general preface—gave me, in my ocean journeyings, not only light, but delight, since facts found their places under it so readily, and derived from it so wide a bearing on the earth's history. In later years have appeared the works of Johnston, Gosse, and Hincks, and the many memoirs of Gray, Forbes, Wright, Duncan, and other workers in science, which have aided largely in giving this department of Zoölogy its present advanced position. Since the subject of polyps is only incidental to the main topic of this volume, I have not had occasion to refer to the details of these memoirs. But the name of Gosse appears often in connection with passages cited from his "British Sea-Anemones;" and I heartily commend his work to all who would appreciate the beauties of

these flower-like animals, and are able to enjoy science when well set forth by a genial author.

Justice to France requires that these allusions to the science of polyps in Great Britain should be followed by a mention of the eminent names of MILNE EDWARDS and JULES HAIME, of Paris, chief among the makers of the science of polyp-corals; and by a reference also to the fact that France, through PEYSONNEL, was ahead in establishing by investigation the animal nature of corals, this observer proving his point at Marseilles, in 1723, on specimens of the very species that had just before been declared to be flowering plants by MARSIGLI, and afterward confirming his results by thirty years of study among the reef-corals of Guadaloupe. It should be added, also, that the rest of Europe has made large contributions to the science, through PALLAS, ESPER, EHRENBERG, and other later investigators. If France, in past times, has taken the lead, she has had the advantage of a sea-coast of more than a thousand miles on the ocean, and of a long line also on the warmer and more prolific Mediterranean.

The discovery of deep-sea corals by recent dredging expeditions has opened up a new field for coral investigations, no less important to Geology than to Zoölogy. But while so much attention has been absorbed in this direction, it should be remembered that the interest of the old coral-fields is far from exhausted, and that one great and most important subject, the rate of growth of corals, and of the increase of reefs, waits for investigators.

JAMES D. DANA.

NEW HAVEN, CONN., *March* 1, 1872.

PREFACE

TO THE SECOND EDITION.

THE principal additions which have been made to this work in the preparation of the second edition are: an abstract of an important paper on the Bahamas, by Captain (now Major-General) NELSON, R.E., read before the Geological Society of London in 1852; an account of the interesting observations of Mr. J. MATTHEW JONES, from *Nature* of August 1872, bearing on the former extent of the Bermudas; facts stated by Mr. S. J. WHITNELL with regard to some Pacific coral islands; and a report of the planting, by MM. LE CLERC and DE BÉNAZÉ, of slabs of coral rock at Tahiti, near the slab placed by Admiral Wilkes, to aid in future determinations of the rate of growth of the Dolphin Shoal, together with a Map of the region. Other minor changes have been made which it is not important here to enumerate.

JAMES D. DANA.

March, 1875.

PREFACE.

THE object in view in the preparation of this work has been to present a popular account of "Corals and Coral Islands," without a sacrifice of scientific precision, or, on the main topic, of fulness. Dry details and technicalities have been avoided as far as was compatible with this restriction, explanations in simple form have been freely added, and numerous illustrations introduced, in order that the subject may have its natural attractiveness to both classes of readers.

I have opened the volume with a chapter on "Corals and Coral Makers," describing, under it, the forms and structure of Polyps; how they live and grow and hold their own in a world of enemies; how coralmaking species secrete their coral; how they multiply, and develop their large clusters, spreading leaves and branching forms, so much like those among plants; and in what seas they thrive, and under what conditions produce the coral plantations.

All this is prefatory to the following part of the volume on Coral Reefs and Islands, which comprises a description of the features and structure of these reef-formations, an account of their mode of accumulation and increase, and a discussion of the origin of the included channels and lagoons, and of the distribution of reefs, together with a review of the facts with reference to their geological bearing.

The observations forming the basis of the work were made in the course of the cruise of the Wilkes Exploring Expedition around the world during the four years from 1838 to 1842. The results then obtained are published in my Report on Zoöphytes, which treats at length of Corals and Coral Animals, and in a chapter on Coral Reefs and Islands forming part of my Geological Report.

The opportunities for investigations in this department afforded by the Expedition were large. We visited a number of the coral islands of the Paumotu Archipelago, to the north of east from Tahiti; also some of the Society, Navigator, and Friendly Islands, all remarkable for their coral reefs; the Feejee Group, one of the grandest regions of growing corals in the world, where we spent three months; several islands north of the Navigator and Feejee Groups, including the Gilbert or Kingsmill Group; the Sooloo sea, between Borneo and Mindanao, abounding in reefs; and, finally, Singapore, another East India reef-region.

Most agreeable are the memories of events, scenes and labours, connected with the cruise:—of companions in travel, both naval and scientific; of the living things of the sea, gathered each morning by the ship's side and made the study of the day, foul weather or fair; of coral islands with their groves, and beautiful life, above and within the waters; of exuberant forests, on the mountain islands of the Pacific, where the tree-fern expands its cluster of large and graceful fronds in rivalry with the palm, and eager vines or creepers intertwine and festoon the trees, and weave for them hangings of new foliage and flowers; of lofty precipices, richly draped, even the sternest fronts made to smile and be glad, as delights the gay tropics, and alive with waterfalls, gliding, leaping, or plunging, on their way down from the giddy heights, and, as they go, playing out and in amid the foliage; of gorges explored, mountains and volcanic cones climbed, and a burning crater penetrated a thousand feet down to its boiling

depths; and, finally—beyond all these—of man emerging from the depths of barbarism through Christian self-denying, divinely-aided effort, and churches and school-houses standing as central objects of interest and influence in a native village.

On the other hand, there were occasional events not so agreeable.

Even the beauty of natural objects had, at times, a dark back-ground. When, for example, after a day among the corals, we came, the next morning, upon a group of Feejee savages with human bones to their mouths, finishing off the cannibal feast of the night; and as thoughtless of any impropriety as if the roast were of wild game taken the day before. In fact, so it was.

Other regions gave us some harsh scenes. One—that of our vessel, in a tempest, fast drifting toward the rocks of Southern Fuegia, and finding anchorage under Noir Island, but not the hoped-for shelter from either winds or waves; the sea at the time dashing up the black cliffs two and three hundred feet, and shrouding in foam the high rocky islets, half-obscured, that stood about us; the cables dragging and clanking over the bottom; one breaking; then another, the storm still raging; finally, after the third day, near midnight, the last of the four cables giving way, amid a deluge of waters over the careering vessel from the breakers astern, and an instant of waiting among all on board for the final crash; then, that instant hardly passed, the loud calm command of the Captain, the spring of the men to the yard-arms, and soon the ship again on the dark, stormy sea, with labyrinths of islands, and the Fuegian cliffs to leeward; but, the wind losing somewhat of its violence and slightly veering, the ship making a bare escape as the morning dawned with brighter skies.

And still another scene, more than two years later, on a beautiful Sunday, in the summer of 1841, when, after a cruise of some months through the tropics, we were in full expectation of soon landing joyously on the shores of the Columbia;

of the vessel suddenly striking bottom; then, other heavier blows on the fatal bar, and a quivering and creaking among the timbers; the waters rapidly gaining, in spite of the pumps, through a long night; the morning come, our taking to the boats, empty handed, deserting the old craft that had been a home for three eventful years, for "Cape Disappointment"—a name that tells of other vessels here deceived and wrecked; and, twenty hours later, the last vestige of the old *Peacock* gone, her upper decks swept off by the waves, the hulk buried in the sands.

But these were only incidents of a few hours in a long and always delightful cruise. If this work gives pleasure to any, it will but prolong in the world the enjoyments of the "Exploring Expedition."

In explanation of some allusions in the following pages, I may here state with regard to the Exploring Expedition, that Captain (now Admiral) CHARLES WILKES, U.S.N., the Commander of the Expedition, was in charge of the Sloop-of-war *Vincennes;* Capt. WM. L. HUDSON, U.S.N., of the Sloop-of-war *Peacock;* Capt. A. K. LONG, U.S.N., of the Storeship *Relief* (the vessel which encountered the dangers in the Cape Horn sea, above related); and Lieut.-Commandant C. RINGGOLD, of the Brig *Porpoise;* and that my associates in the "Scientific Corps" were Dr. CHARLES PICKERING, J. P. COUTHOUY, and TITIAN R. PEALE, Zoölogists; WM. RICH and J. D. BRECKENRIDGE, Botanists; HORATIO HALE, Philologist: JOSEPH DRAYTON and A. T. AGATE, Artists.

Our cruise led us partly along the course followed by Mr. CHARLES DARWIN during the years 1831 to 1836, in the voyage of the *Beagle*, under Captain FITZROY; and, where it diverged from his route, it took us over scenes, similar to his, of coral and volcanic islands. Soon after reaching Sydney, Australia, in 1839, a brief statement was found in the papers of Mr. Darwin's theory with respect to the origin of the atoll and barrier forms of reefs. The paragraph threw a flood of

light over the subject, and called forth feelings of peculiar satisfaction, and of gratefulness to Mr. Darwin, which still come up afresh whenever the subject of coral islands is mentioned. The Gambier Islands, in the Paumotus, which gave him the key to the theory, I had not seen; but on reaching the Feejees, six months later, in 1840, I found there similar facts on a still grander scale and of more diversified character, so that I was afterward enabled to speak of his theory as established with more positiveness than he himself, in his philosophic caution, had been ready to adopt. His work on Coral Reefs appeared in 1842, when my Report on the subject was already in manuscript. It showed that the conclusions on other points, which we had independently reached, were for the most part the same. The principal points of difference relate to the reason for the absence of corals from some coasts, and the evidence therefrom as to changes of level, and the distribution of the oceanic regions of elevation and subsidence—topics which a wide range of travel over the Pacific brought directly and constantly to my attention.

In the preparation of the present work my former chapter on Coral Reefs and Islands has been greatly extended by the addition of facts from numerous sources. The authorities cited from are stated in the course of the volume, and need not here be rementioned. I have occasion, however, for special acknowledgments to our excellent Yale Zoölogist, Professor A. E. VERRILL, who now stands first in the country in the department of Zoöphytes. Through his recent memoirs on the subject, and also by his personal advice, I have been greatly aided in acquainting myself with the present state of the science:—my own special labours in this branch of Zoölogy having ended in 1850, when both the Reports referred to above had been published, and the last of my Expedition departments—that of the Crustacea—forced my studies in another direction.

The illustrations of the following pages have been drawn mainly from my Expedition Reports. Those not my own are

from the works or memoirs of GOSSE, MÖBIUS, VERRILL, POURTALES, L. AGASSIZ, A. AGASSIZ, SMITT, EDWARDS and HAIME, WILKES and HARTT. In addition, the volume is indebted for a few cuts to the beautifully illustrated popular works, "Le Monde du Mer" and "La Vie et les Mœurs des Animaux;" but nearly half of these were engraved from my plates. The sources of all the figures are given in the List of Illustrations.

JAMES D. DANA.

NEW HAVEN, CONN., *Feb.* 12, 1872.

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Isocrymal Chart of the World. Author's Report on Crustacea.
Map of the Feejee Islands. Wilkes's Narrative of the Expl. Exped.
Map of the Florida Reefs, and the Seas between them and Cuba. De Pourtales on Deep-Sea Corals.

CORALS AND CORAL ISLANDS.

CHAPTER I.

CORALS AND CORAL MAKERS.

A SINGULAR degree of obscurity has possessed the popular mind with regard to the growth of corals and coral reefs, in consequence of the readiness with which speculations have been supplied and accepted in place of facts; and to the present day the subject is seldom mentioned without the qualifying adjective *mysterious* expressed or understood. Some writers, rejecting the idea which science had reached, that reefs of rocks could be due in any way to "animalcules," have talked of electrical forces, the first and last appeal of ignorance. One author, not many years since, made the fishes of the sea the masons, and in his natural wisdom supposed that they worked with their teeth in building up the great reef. Many of those who have discoursed most poetically on zoöphytes have imagined that the polyps were mechanical workers, heaping up the piles of coral rock by their united labours; and science is hardly yet rid of such terms as polypary, polypidom, which imply that each coral is the constructed hive or house of a swarm of polyps, like the honeycomb of the bee, or the hillock of a colony of ants.

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Science, while it penetrates deeply the system of things about us, sees everywhere, in the dim limits of vision, the word mystery. Surely there is no reason why the simplest of organisms should bear the impress most strongly. If we are astonished that so great deeds should proceed from the little and low, it is because we fail to appreciate that little things, even the least of living or physical existences in nature, are, under God, expressions throughout of comprehensive laws, laws that govern alike the small and the great.

It is not more surprising, nor a matter of more difficult comprehension, that a polyp should form structures of stone (carbonate of lime) called coral, than that the quadruped should form its bones, or the mollusk its shell. The processes are similar, and so the result. In each case it is a simple animal secretion; a secretion of stony matter from the aliment which the animal receives, produced by the parts of the animal fitted for this secreting process; and in each, carbonate of lime is a constituent, or one of the constituents, of the secretion.

This power of secretion is then one of the *first* and most common of those that belong to living tissues; and though differing in different organs according to their end or function, it is all one process, both in its nature and cause, whether in the Animalcule or Man. It belongs eminently to the lowest kinds of life. These are the best stone-makers; for in their simplicity of structure they may be almost all stone and still carry on the processes of nutrition and growth. Throughout geological time they were the agents appointed to produce the material of limestones, and also to make even the flint and many of the siliceous deposits of the earth's formations.

Coral is never, therefore, the handiwork of the many-armed polyps; for it is no more a result of labour than bone making in ourselves. And again, it is not a collection of cells into which the coral animals may withdraw for concealment any more than the skeleton of a dog is its house or cell; for every part of the coral—or corallum, as it is now called in science—of a polyp, in most reef-making species, is enclosed within the polyp, where it was formed by the secreting process.

It is not, perhaps, within the sphere of science to criticise the poet. Yet we may say in this place, in view of the frequent use of the lines even by scientific men, that more error in the same compass could scarcely be found than in the part of Montgomery's "Pelican Island" relating to coral formations. The poetry of this excellent author is good, but the facts nearly all errors—if literature allows of such an incongruity. There is no "toil," no "skill," no "dwelling," no "sepulchre" in the coral plantation any more than in a flower-garden; and as little are the coral polyps shapeless worms that "writhe and shrink their tortuous bodies to grotesque dimensions."

The poet oversteps his license, and besides degrades his subject, when downright false to nature.

Coral is made by organisms of four very different kinds. These are: *First*, POLYPS, the most important of coral-making animals, the principal source of the coral reefs of the world.

Second, Animals related to the little Hydra of fresh waters, and called HYDROIDS (a division under the Acalephs), which, as Agassiz has shown, form the very common and often large corals called Millepores.

Third, The lowest tribe of Mollusks, called BRYOZOANS, which produce delicate corals, sometimes branching and moss-like (whence the name from the Greek for *moss animal*), and at other times in broad plates, thick masses, and thin incrustations. Although of small importance as reef-makers at the present time, in a former age of the world—the Paleozoic—they so abounded over the sea bottom that some beds of limestone are half composed of them.

Fourth, Algæ or sea-weeds, some kinds of which would hardly be distinguished from corals, except that they have no cells or pores.

I. POLYPS.

A good idea of a polyp may be had from comparison with the garden aster; for the likeness to many of them in external form as well as delicacy of colouring is singularly close. The

aster consists of a tinted disk bordered with one or more series of petals. And, in exact analogy, the polyp flower, in its most common form, has a disk fringed around with petal-like organs called tentacles. Below the disk, in contrast with the slender pedicel in the ordinary plant, there is a stout cylindrical pedicel or body, often as broad as the disk itself, and sometimes not much longer, which contains the stomach and internal cavity of the polyp; and the mouth, which opens into the stomach, is at the centre of the disk. Here then the flower-animal and the garden-flower diverge in character, the difference being required by the different modes of nutrition and other characteristics in the two kingdoms of nature. The coral polyp is as much an animal as a cat or a dog.

The figures of the frontispiece, and others on pages 6, 7, 9, sustain well the description here given, and afford some idea also of the diversity of form among them.

The prominent subdivisions of polyps here recognized are the following:—

I. ACTINOID POLYPS.—Related to the Actinia, or Sea-anemone, in tentacles and interior structure, and having, as in them, the number of tentacles and interior septa a multiple of *six*. The name *Actinia* is from the Greek *ray*.

II. CYATHOPHYLLOID POLYPS.—Like the Actinoids in tentacles and interior structure, except that the number of tentacles and interior septa is a multiple of *four*. Ludwig and De Pourtales state that the number in the earliest young state is *six*, and that therefore the fundamental ratio is the same as in the Actinoids; and that they pass from this ratio by developments of tentacles and septa more rapidly on one side than the opposite, and in such a manner that the number becomes after the first stage a multiple of four. The Cyathophylloid polyps hence combine this characteristic of the Actinoids with one feature of the Alcyonoids. The Cyathophylloids were the earliest of polyps, and the most abundant species in Paleozoic time.

III. ALCYONOID POLYPS.—Having eight fringed tentacles, and other characters mentioned beyond; as the Gorgoniæ and Alcyonia.

I. ACTINOID POLYPS.

The highest of Actinoid Polyps are those of the ACTINIA TRIBE—the species that secrete no coral to clog vital action and prevent all locomotion. The details of structure may be best described from the Actinia or Sea-anemone, and afterward the distinguishing characters of the coral-making polyps may be mentioned. In external aspect and in internal characters all are essentially identical.

I. NON-CORAL-MAKING POLYPS.

As the figures on the frontispiece, and also the following, show, the external parts of an Actinia are—a subcylindrical body—a disk at top—one or more circular series of tentacles making a border to the disk—a mouth, a merely fleshy, toothless opening, at the centre of the disk, sometimes at the summit of a conical prominence—a basal disk for attachment. The upper extremity is called the *actinal* end, since it bears the tentacles or rays, and the lower or base, the *abactinal.*

Sea-anemones vary greatly in colour, and in the distribution of their tints. The lower figure on the frontispiece represents one variety of the *Phymactis clematis* from Valparaiso. Another variety of the same has a rich deep green colour. The upper species on the same plate is one of the gorgeous varieties of the *Phymactis florida* from Callao, Peru. Another is green throughout; and another has a pale bluish-green disk with purplish tentacles, and the papillæ of the body dark sap-green on a pale reddish ground. The other species is the *Bunodes gemma*, from Porto Praya, Cape Verd. It is one of the warty species, and is but partly expanded. The same is shown unexpanded in figure 3*a*, on the right, with disk and tentacles, as usual in this state, wholly concealed.

While often brilliantly coloured, especially in the tropics, other Actiniæ are nearly colourless. This was the case with that represented in the following cut, a species from Long Island Sound near the New Haven Lighthouse, figured some twenty years since by the author, but left undescribed. The

body in this species had a delicate texture throughout, its walls being so transparent that the organs within could be seen through them. It was exceedingly flexible and passed through various shapes, imitating vases of many forms, wine glasses, goblets, &c. It was generally very slow in its changes, and sometimes continued in the same vase-attitude for a whole day.

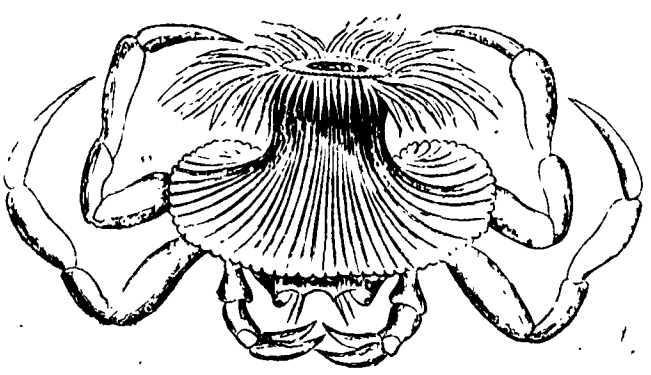


PARACTIS RAPIFORMIS, EDW.

Actiniæ vary immensely in size—from an eighth of an inch and smaller in the diameter of the disk to over a foot—though commonly between half an inch and three inches. One species from the Paumotu Coral Archipelago in the

Pacific, a coloured figure of which is given in the Atlas of the Author's Report on Zoöphytes (Plate III.), had a diameter across its disk of *fourteen* inches; and it was also one of the most beautiful in those seas, having multitudes of tentacles with carmine tips and yellowish bases, around the open centre, gathered into a number of large groups or lobes.

With rare exceptions, Actiniæ live attached to stones, shells, or the sea bottom, or are buried at base in the sand or mud. The attached species have the power of locomotion, through the muscles of the base, but only with extreme slowness. The loose stones on a sea-shore near low tide level often have Actiniæ fixed to their under surface. A very few species swim or float at large in the ocean.



CANCRISOCIA EXPANSA ST., ON THE BACK OF DORIPPE FACCHINO.

Now and then an Actinia puts itself on the back of a crab, and thus secures rapid locomotion, but only at the will of the crab, which may at times give it some hard rubs:—a kind of association styled *commensalism* by Van Beneden, as the two in a sense live at the same table, without preying one upon the other. In the above example, from the China seas, the Actinia has mounted a Dorippe. The figure is from the Proceedings of the Essex Institute, where an account of it is

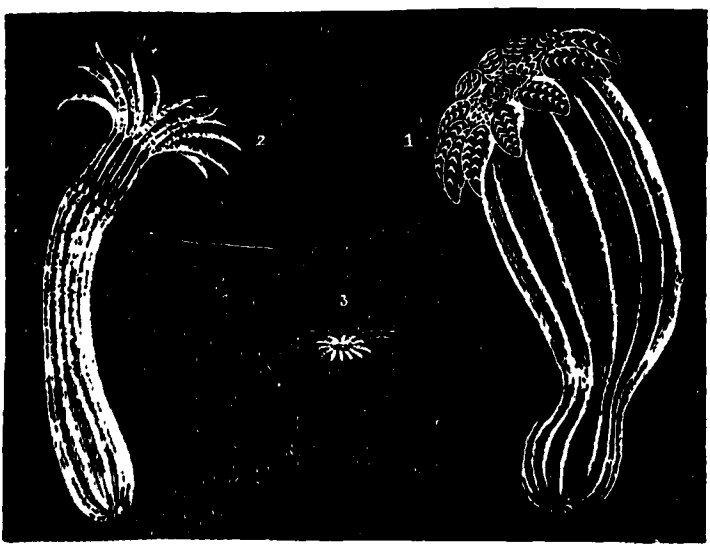
published by Prof. Verrill; the specimen was collected by the Zoölogist, Dr. W. Stimpson. As Prof. Verrill states, the Dorippe carries, for its protection when young, a small shell over its back, which it holds in this position by means of its two reversed pairs of hind legs. The Actinia appears to have fixed itself, when young, to the shell, and afterwards, by its growth, spread over the back of the crab, taking the place of the shell.

This case of commensalism, like most others, is not a mere chance association of species, for the two always go together, the Actinia, according to Dr. Stimpson, never being seen except upon the crab's back, and the crab never without its Actinia. The fact shows an instinctive liking on the part of the Actinia for a Dorippe courser, and for the roving life thus afforded it. And the crab is undoubtedly conscious that he is carrying his fortress about with him. It is not a solitary case; for there are many others of Actiniæ attaching themselves to locomotives—to the claws or backs of crabs, or to shells in possession of soldier crabs, or to a Medusa; and frequently each Actinia has its special favourite, proving an inherited instinctive preference for rapid change of place, and for just that kind of change, or range of conditions, which the preferred commensal provides. Prof. Verrill has an interesting article on this subject, with especial reference to crustaceans, in the third volume of the *American Naturalist.*

Species living in sand are often unattached; and then the base is rounded or tapering, and sometimes balloon-shaped; some of them are long and almost worm-like, and even burrow like worms.

The following are figures of three species: one, figure 3, exhibiting simply the tentacles and disk of the Actinia, the only parts visible above the sand; the others showing the whole body removed from the sand, and consequently a little out of shape. They are from Gosse's "British Sea-Anemones," in which they are given with the natural colours. Figure 1 represents the *Peachia hastata* of Gosse, a beautiful species having twelve large tentacles; figure 2 the *Edwardsia callimorpha*

G.; figure 3, *Halocampa chrysanthellum* G. Most of these sand-dwellers bury themselves like the Halocampa, and often hide all the disk but the mouth. The Edwardsia is peculiar in having, above the hollow bladder-like basal portion, a firm opaque exterior to the body, making for it a kind of case or jacket, into which the upper extremity, which is soft and delicate in texture, may be retracted. The thickening of the

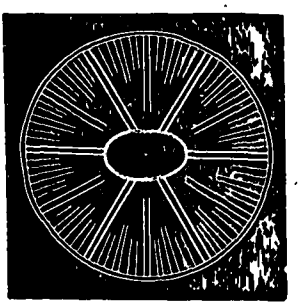


ACTINIÆ.

epidermis in this middle portion is produced through the entangling of disintegrated cells and minute foreign particles, sometimes in part spores of Confervæ, by means of the mucus of the surface; and if the layer is removed, as it may be, the skin will again become covered. This species, like others of the genus, lives buried to its neck in the sand, that is, with the soft upper extremity protruding. If disturbed, the head is suddenly drawn in, together with more or less of the following jacketed part of the body.

The warty prominences on some warty species have the power of clinging by suction to a surface, and such Actiniæ often cover their sides thus with bits of shell or of other substances at hand. Where there are no warts the contracted exterior skin, reticularly corrugated, occasionally becomes a surface of suction-warts, as in many Sagartiæ.

The *internal structure* of the Actinia is radiate like the external, and more profoundly and constantly so. The mouth, a fleshy toothless opening in the disk, opens directly into a stomach, which descends usually about a third of the way to the base of the body; its sides are closed together unless it be in use. The general cavity of the body around and below the



stomach is divided radiately by fleshy partitions, or septa, into narrow compartments; the larger of these septa connect the stomach to the sides of the animal, and, besides holding it in place, serve to pull it open or distend it for the reception of food. The above figure represents in a general way a horizontal section of the body through the stomach, and shows the position of the radiating septa and the intermediate compartments. It presents to view the fact that these are in pairs, and another fact that the number of pairs of partitions in the ordinary Actinoid polyps is regularly some multiple of six, although other numbers occur during the successive developments that take place in the growth of a polyp, and are

occasionally persistent in the adult state. There are six pairs in the first series; *six* in the second; *twelve* in the third; *twenty-four* in the fourth; *forty-eight* in the fifth, and so on.

The compartment between the two septa of each pair opens at top into the interior of a tentacle, and thus the cavity in each tentacle has its special corresponding compartment below. This tentacular compartment is properly, as first recognized by Prof. Verrill, the *ambulacral*, since each corresponds in position and function to an ambulacral or tentacle-bearing section in the Echinoderms and other Radiate animals.

Although polyps are true Radiates, they have something of the antero-posterior (or head-and-tail) polarity, with also the right-and-left, which is eminently characteristic of the animal type. This is manifested in the occurrence in some polyps of a ray on the disk different in colour from the general surface; of one tentacle larger than the others, and sometimes peculiar in colour; of two opposite septa in a calicle or polyp-cell larger than the others, and sometimes meeting so as to divide the cell into halves. The first of these marks the author has observed in a Zoanthid, as mentioned in his Report on Zoöphytes at page 419, and represented on plate 30: and the last is very strongly developed in the cells of many Pocilloporæ (ib. p. 523). Gosse and many other authors have drawn attention to the one large tentacle, and the fact that it lies in the direction of the line of the mouth. Prof. H. James Clark, in his "Mind in Nature," states that the order in which the fleshy septa and the tentacles in an Actinia are developed has direct reference to the right and left sides of the body, and that there is only one plane in which the body can be divided into two halves, and this is that corresponding with the longer diameter of the stomach, or the direction of the mouth. Mr. A. Agassiz has shown that in Actiniæ of the genus Arachnactis, the new septa and tentacles are developed on either side of the one chief or anterior tentacle: and Prof. Verrill, that in Zoanthids they are formed principally on either side of this anterior tentacle and also of the opposite or posterior one, and much less rapidly, if at all, along the sides intermediate. This chief-tentacle marks properly

the true front or anterior side of the polyp. A fore-and-aft structure is also very strongly marked in some of the ancient cyathophylloid corals, and hence it belonged to the type from early Paleozoic time.

The way leading out from the Radiate structure is thus manifested by these flower-like polyps. In fact perfect circular series in organs or parts do not belong to any living organism, not even to the true flower; for growth is fundamentally spiral in its progress, and there must be always an advance end to the spiral of growth; all apparent circles are only disguised spirals.

The walls of the body contain two sets of muscles, a circular and a longitudinal, the latter becoming radial in the disk and base. Similar muscles exist also in the tentacles, and corresponding muscles in the fleshy partitions or septa of the internal cavity.

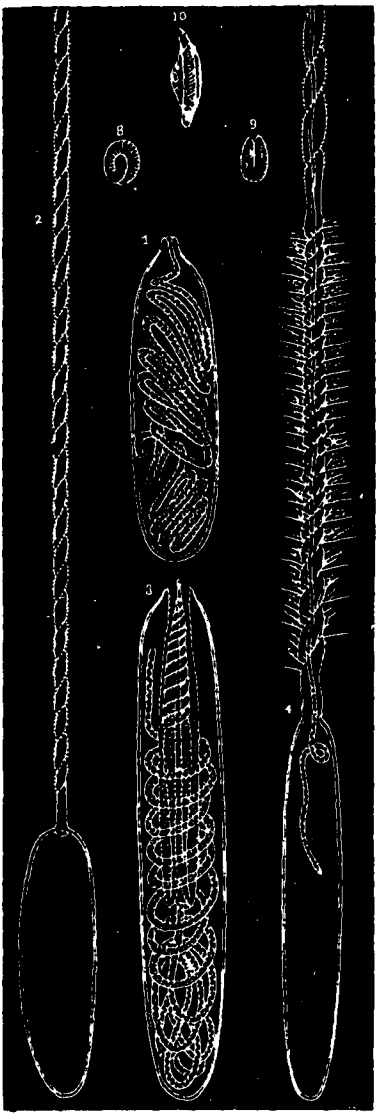
By means of these muscles an Actinia, whenever disturbed, contracts at once its body; and most species make of themselves a spheroidal or conoidal lump, showing neither disk nor tentacles. One example of this contracted state is presented on the frontispiece in figure 3*a*. After a brief period of quiet the polyp commonly reassumes its full expansion. The expansion depends on an injection of the structure with salt water, which is taken in mainly by the mouth. As the whole body is thus filled and injected, the flower slowly opens out, and shows its petal-like tentacles. On contraction the water is suddenly expelled through the mouth, and by pores in the sides of the polyps, and at the extremity of the tentacles, and the tentacles disappear, along with the disk, beneath the adjoining sides of the body which are drawn or rolled in over them.

The Actinia appears, at first thought, to be well prepared for securing its prey through its numerous tentacles. But these are generally too short for prehension. Yet the disk often aids them by rolling over the captured animal, and pushing it down into the stomach. At the same time, the mouth and stomach are both very extensile, so that an Actinia may swallow an animal nearly as large as itself; it gradually stretches the

margins of the mouth over the mollusk or crab, until the whole is inclosed and passed into the digestive sac; and when digestion is complete, the shell and any other refuse matters are easily got rid of by reversing the process.

But the Actinia owes nearly all its power of attack to its concealed weapons, which are carried by myriads. These are what Agassiz has called *lasso-cells*, because the little cell-shaped sheath contains a very long slender tubular thread coiled up, which can be darted out instantly when needed. As first observed by Agassiz, the tubular lasso escapes from the cell by turning itself inside out, the extremity showing itself last, and this is usually done "with lightning-like rapidity." Then follows the poison. The lasso-cells (called often *nettling cells*, and by Gosse *cnidæ*, and *thread capsules*) are usually less than a 200th of an inch in length; but they are thickly crowded in the larger part of the skin or walls of the tentacles, and about the mouth; also in the walls of the stomach, and within the visceral cavity in white cords hanging in folds from the edge of the septa. Thus the polyp is armed inside and out. The mollusk or crab that has the ill luck to fall, or be thrown by the waves, on the surface of the pretty flower is at once pierced and poisoned by the minute lassos, and is rendered incapable of resistance.

The following figures, by Dr. Karl Mobius, of Hamburg, illustrate admirably these organs. The views are magnified 700 diameters. Figure 1 represents one of the lasso-cells of the Actinia, *Corynactis viridis*, with its lasso coiled up within; its actual length is about a 350th of an inch. Figure 2 is the same with the lasso out, though less than half of the long thread is shown. Figure 3 is the lasso-cell of the polyps of a European coral, the *Caryophyllia Smithii*. It differs from figure 1 in having the basal part of the lasso within the cell or sheath strait and stout; it is this part which makes the first portion of the extended lasso. A view of part of the latter is represented in figure 4, and of the extremity of the same in figure 5. The lasso-cells in the above species are from a 240th to a 360th of an inch in length. In the *Metridium margina-*



tum, an American Actinia occurring along the coast of the United States, north of New York, the length of one of the lasso-cells, according to Dr. Leidy, was about a 400th of an inch, and the character of the extended lasso was much like that of figure 4. The lower part of the lasso, for a length 1½ times or more longer than the cell or sheath, is usually thickened, and sometimes slenderly spindle-shaped, while the rest is an even slender thread; and the thickened part, and sometimes all the rest, as above shown, is spirally wound by a slender line, sometimes elevated, set with short hairs or bristles. The thread-like portion may be wanting or very short. The lasso is often twenty times as long as the cell or sheath, and occasionally forty times; but if the thread-like part is absent, only one and a half to two times.

A lasso-cell once used

is afterward worthless; for the tube cannot be returned to the sheath. But those thus expended are not missed, as the polyp has indefinite supplies of such weapons, and also ready means of refurnishing itself.

Figures 6, 7, 8, 9, 10, pp. 14, 15, illustrate different stages in the development of a lasso-cell (figure 10) out of a common spherical cell, as made out by Dr. Mobius in his careful microscopic investigations. The Actinia affording the results was the *Urticina crassicornis*, found in both European and American seas. The actual size of the cell represented in figure 6 is about a 5000th of an inch. In figure 7 the lasso-cell has already taken form but is folded on itself; in 8, there is a second infolding; 9 shows a return to a single fold, and further progress in the forming cell; and 10, the straightened lasso-cell. Thus the work of replenishing, throughout the body wherever lassos are used, is always going on.



The radiating partitions or septa in the internal cavity of the polyp have along the outer free edge what looks like a slender white cord attached to it by a much convoluted or mesentery-like membrane; and this cord contains vast numbers of lasso-cells radiately arranged. These white cords through the multiplied plaitings of the mesenteric membrane have great length; and they sometimes extend up through the stomach and pass out of the mouth; or they are extended in loops through the walls wherever they may happen to be torn.

There are often also bunches of somewhat similar white cords full of lasso-cells appended to the septa, which are extended from the body through some natural orifices near the base of the Actinia (especially those of the Sagartia family). Gosse calls these cords *Acontia*. They extend out usually two or three inches, and sometimes six inches, and thereby widen much the stinging range of an Actinia, both for the purposes of defence and attack.

Gosse, in his "British Sea-Anemones," gives the results of some experiments with regard to the action of these lasso-cells (*cnidæ*), from which a few paragraphs may be here cited.

"It has long been known, that a very slight contact with the tentacles of a polyp is sufficient to produce, in any minute animal so touched, torpor and speedy death. Since the discovery of these *cnidæ* (lasso-cells) the fatal power has been supposed to be lodged in them. Baker, a century ago, in speaking of the Hydra, suggested that 'there must be something eminently poisonous in its grasp;' and this suspicion received confirmation from the circumstance that the *Entomostraca* which are *enveloped in a shelly covering* frequently escape unhurt after having been seized. The stinging power possessed by many Medusæ, which is sufficiently intense to be formidable even to man, has been reasonably attributed to the same organs, which the microscope shows to be accumulated by millions in their tissues.

"Though I cannot reduce this presumption to actual certainty, I have made some experiments, which leave no reasonable doubt on the subject. First—I have proved that the *ecthoræum* (tubular thread of the lasso-cell) when shot out, has the power of penetrating, and does actually penetrate, the tissues of even higher animals. Several years ago, I was examining one of the purple *acontia* of *Adamsia palliata;* no pressure had been used, but a considerable number of *cnidæ* had been spontaneously dislodged. It happened that I had just before been looking at the sucker-foot of an Asterina, which remained still attached to the glass of the aquatic box, by means of its terminal disk. The cilia of the *acontium* had, in their rowing action, brought it into contact with the sucker, round which it then continued slowly to revolve. The result I presently discovered to be, that a considerable number of *cnidæ* had shot their *ecthoræa* into the flesh of the sucking-disk of the Echinoderm, and were seen sticking all round its edge, the wires (lassos) being imbedded in its substance even up to the very capsules, like so many pins stuck around a toilet pincushion.

"To test this power of penetration still farther, as well as to try whether it is brought into exercise on the contact of a foreign body with the living Anemone, I instituted the follow-

ing experiment. With a razor I took shavings of the cuticle from the callous part of my own foot. One of these shavings I presented to the tentacles of a fully-expanded *Tealia crassicornis* (*Urticina crassicornis* of Europe and America). After contact, and momentary adhesion, I withdrew the cuticle, and examined it under a power of 600 diameters. I found, as I had expected, *cnidæ* standing up endwise, the wires in every case shot into the substance. They were not numerous—in a space of ·01 inch square, I counted about a dozen. . . .

"These examples prove that the slightest contact with the proper organs of the Anemone is sufficient to provoke the discharge of the *cnidæ;* and that even the densest condition of the human skin offers no impediment to the penetration of the *ecthoræa.*

"As to the injection of a poison, it is indubitable that pain, and in some cases death, ensues even to vertebrate animals from momentary contact with the capsuliferous organs of the Zoöphyta. . . . I have elsewhere recorded an instance in which a little fish, swimming about in health and vigour, died in a few minutes with great agony through the momentary contact of its lip with one of the emitted *acontia* of *Sagartia parasitica.* It is worthy of observation, that, in this case, the fish carried away a portion of the acontium sticking to its lip; the force with which it adhered being so great, that the integrity of the tissues yielded first. The acontium severed, rather than let go its hold.

"Now, in the experiments which I have detailed above, we have seen that this adhesion is effected by the actual impenetration of the foreign body by a multitude of the *ecthoræa* whose barbs resist withdrawal. So that we can with certainty associate the sudden and violent death of the little fish with the intromission of barbed *ecthoræa.*"

The following observation by J. P. Couthouy, from the author's Report on Zoöphytes (p. 128), if it is beyond question, shows power even in the Actinia's presence. "Having a number of Monodontas (a genus of univalve Mollusca allied to our Trochi), too much crowded in a large jar of water, I

took out half-a-dozen, and placed them in a jar with an Actinia (*Anthea flagellifera*). On looking at them about three hours after, I found that, instead of climbing like the others to the top of the water, they remained just where they had fallen, closely withdrawn into their shells. Supposing them to be dead, they were taken out, when they directly began to emerge; and when returned to the jar with the other Monodontas, they were in less than five minutes clustered round its mouth. On placing them again in the jar with the Actinia, though kept there for two hours, they did not once show themselves out of the shell. Once more placing them along with the other shells, they exhibited their former signs of life and activity. The experiment was repeated several times with a large Littorina, with the same result, evincing fear of the Actinia on the part of the Mollusks."

Gosse gives the following fish story, which is much to the point. Speaking of the *Anthea cereus*, or Opelet, a British species, he says (p. 168):—"I one day saw an amusing example of its power of passive resistance. A beautiful little specimen of the variety *alabastrina*, which had been sent to me by Mr. Gatehouse, I had occasion to remove from one tank to another. There was a half-grown Bullhead (*Cottus bubalis*) at the bottom, which had been in captivity rather more than a fortnight. As he had not been fed during that time, I presume he was somewhat sharp-set. He marked the Anthea falling, and before it could reach the bottom, opened his cavern of a mouth and sucked in the *bonne bouche*. It was not to his taste, however, for as instantly he shot it out again. Not discouraged, he returned to the attack, and once more sucked it in, but with no better success; for, after a moment's rolling of the morsel around his mouth, out it shot once more; and now the Bullhead, acknowledging his master, turned tail, and darted into a hole on the opposite side of the tank in manifest discomfiture."

He adds:—"But if you, my gentle reader, be disposed for exploits in gastronomy, do not be alarmed at the Bullhead's failure: only take the precaution to 'cook your hare.' Risso calls this species '*edulis*,' and says of it—'*On le mange en*

friture,' and I can say, '*Probatum est.*' No squeamishness of stomach prevents our volatile friends, the French, from appreciating its excellence; for the dish called *Rastegna*, which is a great favourite in Provence, is mainly prepared from *Anthea cereus*. I would not dare to say that an Opelet is as good as an Omelet; but *chacun à son goût*—try for yourselves. The dish is readily achieved."

The stomach, although without a proper sphincter muscle at its inner extremity, appears to be closed below during the process of digestion. When digestion is complete, the refuse from the food is pushed out through the mouth, the only external opening to the alimentary cavity, and the digested material passes downward into the interior cavity; and there, mixed with sea-water from without, it is distributed through all the interior cavities of the polyp for its nutrition. The polyp has no circulating fluid but the results of digestion mixed with salt water, no blood-vessels but the vacuities among the tissues, and no passage-way for excrements excepting the mouth and the pores of the body that serve for the escape of water on the contraction of the animal.

Actiniæ have usually no gills or *branchiæ* for the aeration of the blood, the whole surface of the body being ordinarily sufficiently soft and delicate to serve in this function. Some species live half buried in the sand, and, as this in large species would prevent the skin of the sides from aiding in respiration, there are sometimes very much lobed and crimpled organs, attached to, or alongside of, the tentacles, which give the animal-flower much greater beauty, and at the same time increase the extent of surface for the purposes of aeration; they are set down as branchial by Prof. Verrill.

In one tribe of polyps closely related to the Actiniæ, the Zoanthids, in which the outer skin is usually somewhat corriaceous, or is filled with grains of sand, there are narrow gills arranged vertically, one on either side of the larger radiating septa, figures of which are given in the author's Zoöphyte Atlas.

As to *senses*, Actiniæ, or the best of them, are not quite as

low as was once supposed. For, besides the general sense of feeling, some of them have a series of eyes, placed like a necklace around the body, just outside of the tentacles. The yellow prominences in this position on the larger figures in the frontispiece are these eyes. They have crystalline lenses, and a short optic nerve. Yet Actiniæ are not known to have a proper nervous system: their optic nerves, where they exist, are apparently isolated, and not connected with a nervous ring such as exists in the higher Radiate animals.

Reproduction is carried forward both by ova and by buds, though the latter method is mostly confined to the coral-making polyps.

The ovarian and spermatic functions belong to the radiating septa in the interior cavity of the Actinia, and to the part of a septum, mesenteric in character, at or near the outer margin. They have the aspect of a pulpy mass, or look like clusters of ovules. The ova have no chance for escape except through the stomach and mouth. They are covered with vibratile cilia, and rove about free for a while. As the development of the embryo goes forward, a depression begins at one end, which deepens and becomes a stomach, with the entrance to it as a mouth. Concurrently, septa grow out from the inner wall, and a few tentacles commence to rise around the mouth. Not unfrequently, the young has already some of its tentacles before it leaves the parent. There is at first but a single row of tentacles; the number increases with the size until the full adult limit is reached, the newer series being successively the outer.

In the budding process, which is of rare occurrence, Actiniæ grow young ones on their sides near the margin of the base. A protuberance begins to rise and soon shows a mouth, and then becomes surrounded by tentacles; and, thus begun, the new Actinia continues to grow, usually until its tentacles have doubled their number, when finally it separates from the parent and independent animal. At times, as Prof. H. James Clark has observed, small pieces of the base of an Actinia separate by a natural process before a trace of a tentacle has

appeared, and in this case "they do not at first show any signs of activity, but on the contrary remain for a long time in a quiet state, having the appearance of artificially separated pieces, seeming to be undergoing, as in the latter, a recuperative process after the shock of a separation." After a while they commence to develop and grow into perfect individuals. Prof. Verrill mentions the case of an Actinia from Puget's Sound (the *Epiactis prolifera*, V.) which had three rows of young individuals attached to it around the middle of its body; but whether the young Actiniæ were produced by budding from this part of the body, or whether they had colonized there after being produced in the ordinary way, he was unable to determine. In all cases the young ultimately separate from the parent.

These polyps have also the faculty of reproducing lost parts; and to such an extent that a mere fragment, if it be from the lower part, and include a portion of the base, will reproduce all the rest of the Actinia, even to the disk, tentacles, and stomach. Thus the mere forcible tearing of an Actinia from the rock to which it is attached may result in starting a crop of new Actiniæ.

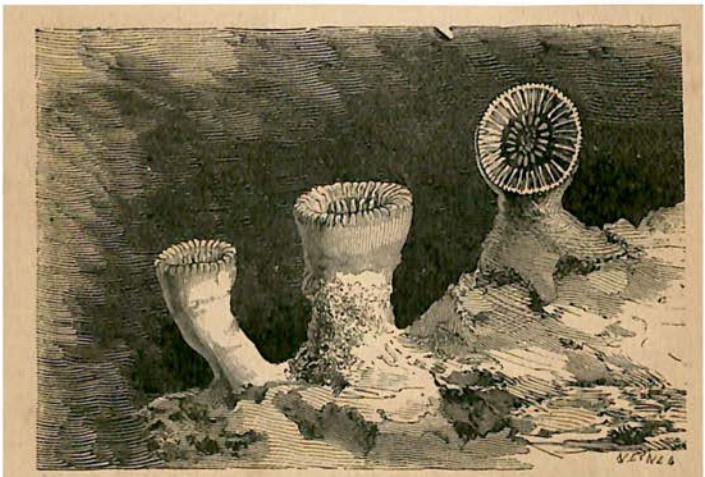
Although Actiniæ have no internal coral secretions, they sometimes make a thickened epidermic plate at the base, and also in a few cases around a part of the body. This is however not a result simply of an epidermic secretion, but arises from an exudation of mucus from the surface, and the entangling thereby of minute particles of foreign or dead matters. A case of the kind, in an Edwardsia where the body is thus encased, is mentioned and explained on page 9.

The above are the more prominent characters of the Actinia tribe of polyps. The special features distinguishing them from the coral-making polyps are the following: (1) They are simple animals, or, if they bud, the buds early separate from the parent; (2) They have a muscular base; (3) They are generally capable, more or less perfectly, of locomotion on the base by means of its muscles; (4) They sometimes possess rudimentary eyes; (5) They have no internal coral secretions.

Each of these characters is evidence of the superior grade of this division of polyps.

II. CORAL-MAKING ACTINOID POLYPS.

Of the form, tentacles, mouth, stomach, fleshy septa, lasso-cells, food, digestion and respiration of the coral-making polyps here included, nothing need here be said, these characters being the same as in the Actiniæ. Their more striking peculiarities depend on the secretion of coral, making them fixed species, and involving an absence of the base; and, in the



CARYOPHYLLIA CYATHUS.

case of the majority of the species, on the extent to which they multiply by buds, in imitation of species in the vegetable kingdom.

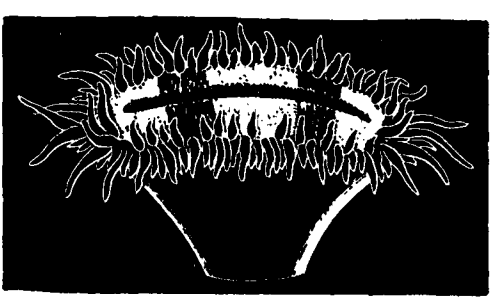
The coral skeleton which the secretions of polyps form is called the *corallum*. These secretions take place among the tissues of the sides and lower part of the polyp, but never in the disk or stomach, as this would interfere with the functions of these organs. In the above sketches of a simple coral,

from the Mediterranean, the upper extremity is a depression, or *calicle*, inclosed by a series of radiating calcareous (coral) *septa*. Each of these septa is secreted between a pair of the radiating fleshy partitions, or septa, of the polyp (see figure p. 10); and thus the radiate structure of ordinary corals is nothing but an expression of the internally radiate structure of the polyp. When alive, the top, and usually the sides, of the coral were concealed by the outer skin of the polyp, including, above, the disk and tentacles; and into the depression or calicle at top, descended the stomach.



THECOCYATHUS CYLINDRACEUS.

Whether these radiating septa of the coral are secreted from the surfaces of the fleshy septa, or from a prolongation inward of the membrane forming the walls of the internal cavity, has not been directly ascertained. The latter view is sustained by Professor Verrill, on the ground that the coral septa contain fibres of animal tissue. The secretion does not always commence at the central plane of a septum, for the septa are sometimes hollow within, just as the surface spines of some



FLABELLUM PAVONINUM.

species (e.g., *Echinopora reflexa*) are hollow. The exterior surface of the corallum, that is, the part outside of the calicles,

is often ribbed, and the ribs are ordinarily only an outer extension of the interior septa; so that surface spines are in fact but the outer margins of septa.

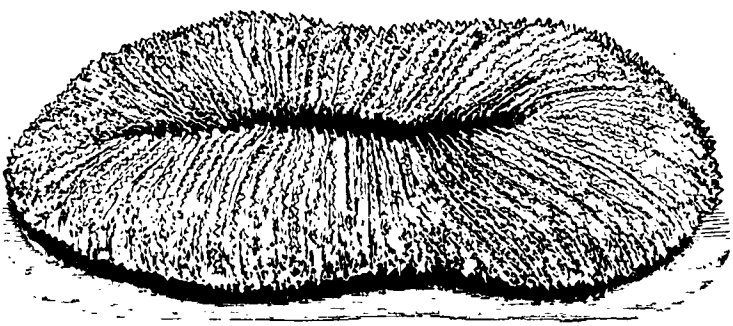
The first of the preceding figures, representing *Thecocyathus cylindraceus*, Sourt, exhibits another of the forms of these simple corals. It is described by Pourtales, from specimens collected by him at a depth of 100 to 200 fathoms off the Florida reef. The actual size was one-third that of the figure. The second figure represents a living species, the *Flabellum pavoninum*, described and figured by the author from specimens obtained at Singapore.

The bottom of the *calicle*, or polyp-cell, in the corallum is sometimes made simply by the meeting of the radiating septa; occasionally by the same, with the addition of a point or *columella* at the centre; often by a twisting together of this part of the radiated septa. Very often, also, it is a mere porous mass. Sometimes there is a circle of prominent points about the centre, as seen in the figure of a Caryophyllia on page 22, which are the extremities of narrow vertical strips (called *pali*) lying in the planes of the septa. Similar points exist in the Thecocyathus on the preceding page, though not in sight in the figure.

In many cases the bottom is quite solid; and this may be so either (1) because the coral secretions fill up all the pores as the polyp increases in age, and thus make the interior of the corallum solid or nearly so; or (2) because there are formed periodically, as the polyp grows upward, solid horizontal plates across the bottom, so that beneath, in the interior of the corallum, there is a series of plates or tables with spaces between. The Pocilloporæ, among recent corals (page 70), and the Favosites among ancient, are examples. Increasing solidity with the increasing age of the polyps is also produced at times by additions to the exterior of a corallum. In many species, the skin, over part or all of the exterior, gradually disappears or dies away and leaves the corallum bare, while all is living within; and in such cases the skin, before disappearing, often adds a layer of stony material to the exterior,

giving greater firmness to the whole. An example is shown in the figure on page 22. In such a case, there is no skin or animal tissue over the outside of the corallum, excepting at its upper extremity, above this calcareous coating.

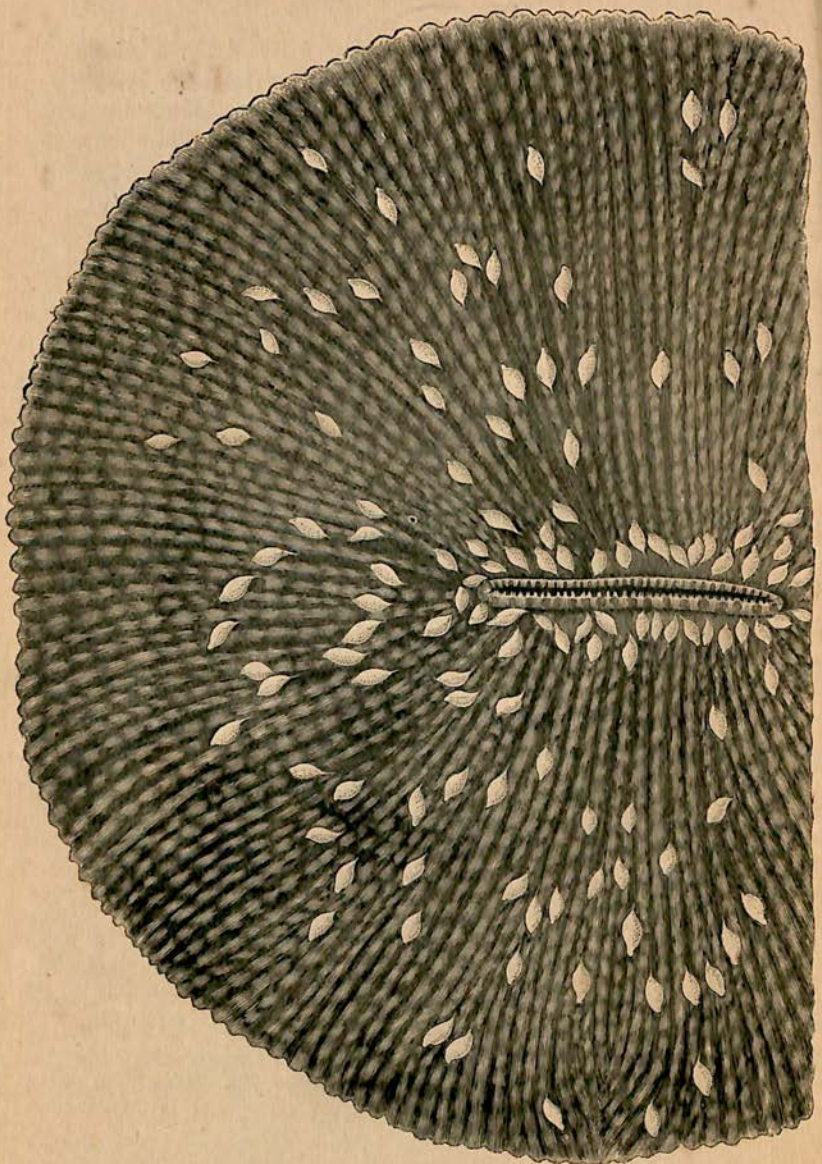
Another form of a corallum, the secretion of a single polyp, is illustrated in the following figure of a species of the Fungia family, so-called in allusion to a resemblance to the mushroom. The long mouth occupied a considerable part of the longitudinal central line. From the line at the centre, there is the same radiated arrangement of calcareous septa as in the preceding species, though the animal differs greatly in its



CTENACTIS ECHINATA.

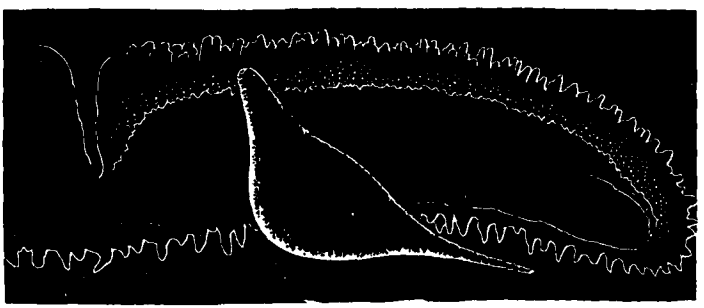
extreme shortness in proportion to the breadth. The corals of this group are also peculiar in having the radiated upper surface flat, or nearly so, instead of concave. The figure is a fourth the natural size. These corals, of the genus Fungia, often exceed a foot in length; and thus coral animals are sometimes as large as the largest of Actiniæ.

Another species of this genus, the *Fungia lacera*, V. (formerly *Fungia echinata*, D., from the Feejees), is represented as it appears when living (excepting a part left off to suit the page) in the following figure. The coral in the perfect state of the animal is wholly concealed, though often showing the points of the teeth of the septa in consequence of the skin being broken.



FUNGIA LACERA, V.

An enlarged view of one of the tentacles is given below. They are very small, compared with the size of the polyp; and this is true of all the living Fungiæ studied by the author. It is plain that the power of such tentacles must reside wholly in their lasso-cells.



TENTACLE OF FUNGIA LACKRA.

The tentacles are scattered over the disk, instead of being in regular circles. It is evident from the figure that the apparent circles, where there is more than one, in Actiniæ, arise from the crowding of the series of tentacles together; and also that the inner row of tentacles in polyps is the older. It will be noticed also that each of the tentacles stands where a new ridge (or calcareous septum in the coral) begins.

The Fungiæ, unlike most corals, are not fixed animals except in the young state. They are common in coral-reef seas, lying over the sandy or rocky bottom between the other corals.

Other varieties of corals and coral animals are illustrated in the figures on the following pages. They represent *compound groups*, in which great numbers of polyps are connected in a single zoöphyte—a result, in part, of the process of budding already alluded to, and partly of different modes of growth connected therewith.

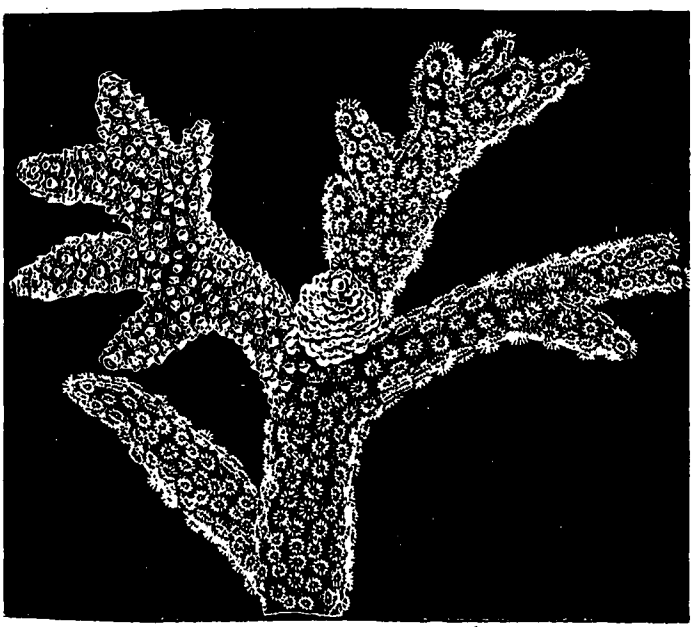
This budding is very similar to the budding process in vegetation. One common method is the same that is occa-

sionally met with in Actiniæ, the description of which is briefly given on page 20. The bud commences as a slight prominence on the side of the parent. The prominence enlarges, a mouth opens, a circle of tentacles grows out around it, and increase continues till the young finally equals the parent in size. Since in these species the young does not separate from the parent, this budding produces a compound group; and the process often continues until in some instances thousands, or hundreds of thousands, have proceeded from a single germ, and the colony has increased to a large size, sometimes many feet, or even yards, in breadth or height. Such is the species of Dendrophyllia represented in the figure on page 31, and the Madrepora figured on page 29; in both of which, and in all such coral zoöphytes, each stellate cavity or prominence over the surface corresponds to a separate one of the united polyps.

The compound mass produced by budding—which consists of the united polyps with the corallum as their united secretion—was called in the Author's Report, a Zoöphyte, it being truly animal in nature, though under a plant-like form through the plant-like process of budding. But the word to many minds conveys the idea that the species is something *between* a plant and an animal, which is totally false; and besides, it is often used distinctively for the division of animals including the sponges. As a substitute the term *Zoöthome* may be employed, derived from the Greek ζωον, *animal*, and θωμος, a *heap*—a term applicable also to compound groups in other classes, as, for example, those of Rhizopods, Bryozoans and Ascidians. The term zoöphyte, where employed beyond, signifies a zoöthome formed of united polyps, or a *polyp-zoöthome*. The coral of the zoöthome being the *corallum*, that of each polyp in the compound corallum may be called a *corallet*—the term *calicle*, formerly used by the author for the same, being now restricted to the polyp-cell.

It is obvious that the connection of the polyps in all compound groups must be of the most intimate kind. The several polyps have separate mouths and tentacles, and separate

stomachs; but beyond this there is no individual property. They coalesce, or are one, by intervening tissues; and there is a free circulation of fluids through the many pores or lacunes. The zoöthome is like a living sheet of animal matter fed and nourished by numerous mouths and as many stomachs.



MADREPORA ASPERA, D.

Polyps thus clustered constitute the greater part of the flowering zoöphytes of coral reefs. Only a few are simple animals, like the Caryophyllia figured on page 22, or the Thecocyathus, page 23, or the Fungia, page 26.

This kind of budding may take place from the sides of the polyp at different heights; either (1) from the base, as in the Actinia mentioned on page 20 when it is *basal;* or (2), above

the base, when it is called *lateral;* or (3) at the upper margin outside of the tentacles, when it is called *marginal* or *superior;* or (4) from the disk inside of the tentacles.

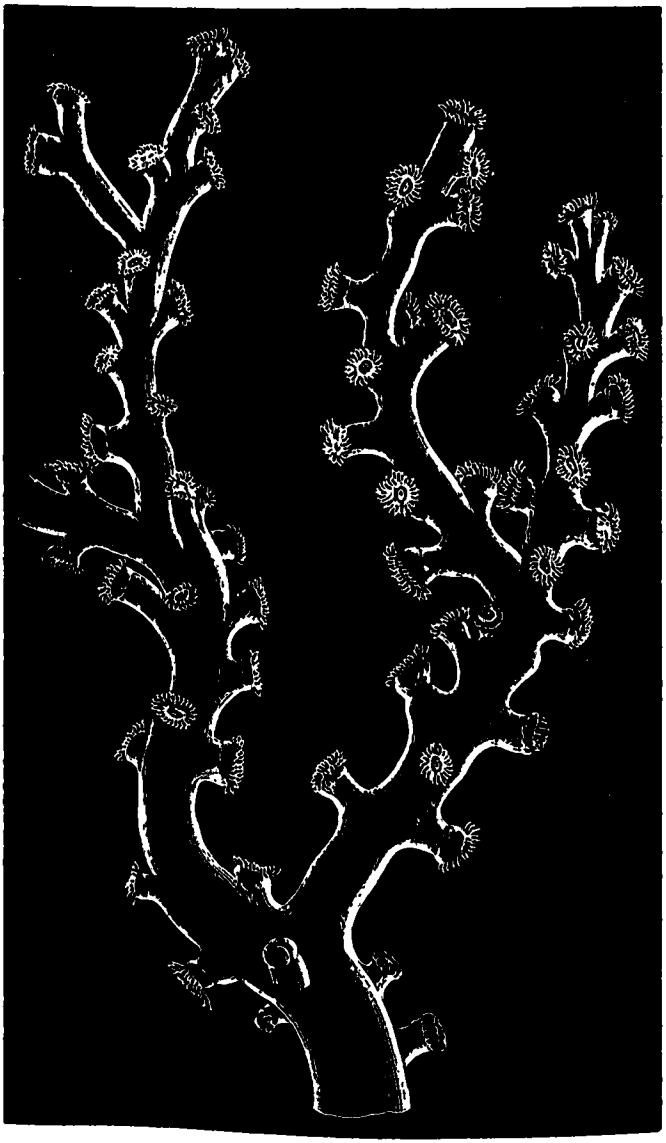
Sometimes a shoot grows out from one point only of the base of a polyp, like the stoloniferous stem from a strawberry plant, and at short intervals gives off buds; and thus makes a linear zoöphyte with a row above of flower-animals. In other cases, the base spreads in all directions and buds at the edge, or in the upper surface near the edge, and so makes an incrusting plate consisting of a multitude of polyps.

If the germ polyp, or that from which the compound zoöphyte proceeds, has the property of growing upward beyond the adult height—which the existence of coral renders a possibility, and even to an indefinite degree—various other forms may result.

Sometimes the first polyp gives out buds from its sides, and continues so to do when it grows upward; and thus a rising stem is formed with one parent polyp at the extremity of the stem, and a terminal corallet to the corallum, or to each branch of it. This is the case in the genus *Madrepora*, a species of which is represented on the preceding page. Each branch in the living state had at its extremity the parent polyp of the branch, or that whose budding made the other polyps of the branch. In such species, a new lateral branch is commenced by one, among the many polyps over the surface of a branch, beginning to grow and bud. Thus branch after branch is added, and the little tree produced.

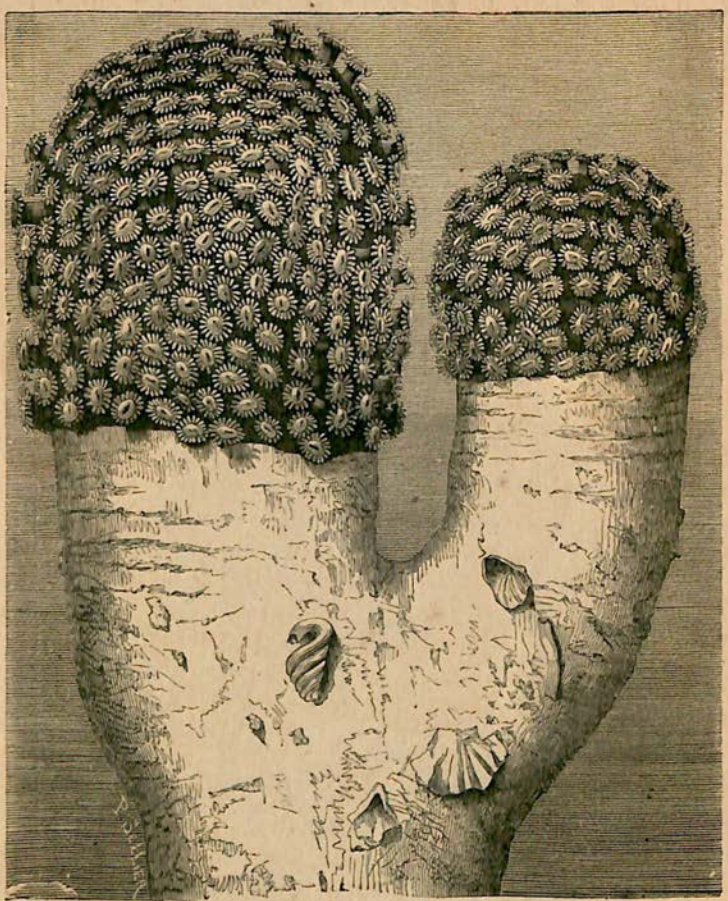
Another kind of coral, growing and budding in the same manner, is represented on page 31. It is a species of Dendrophyllia, from the Feejees—a genus often representing tree-like forms, as the name implies.

In other cases, budding goes on until a cluster of some size is formed, and then the older or marginal polyps of the cluster cease budding while the rest continue the process; in this way a stem rises, with the budding cluster of polyps at its summit, and the more aged, or non-budding polyps, about its sides; and the breadth of the stem depends on the size of



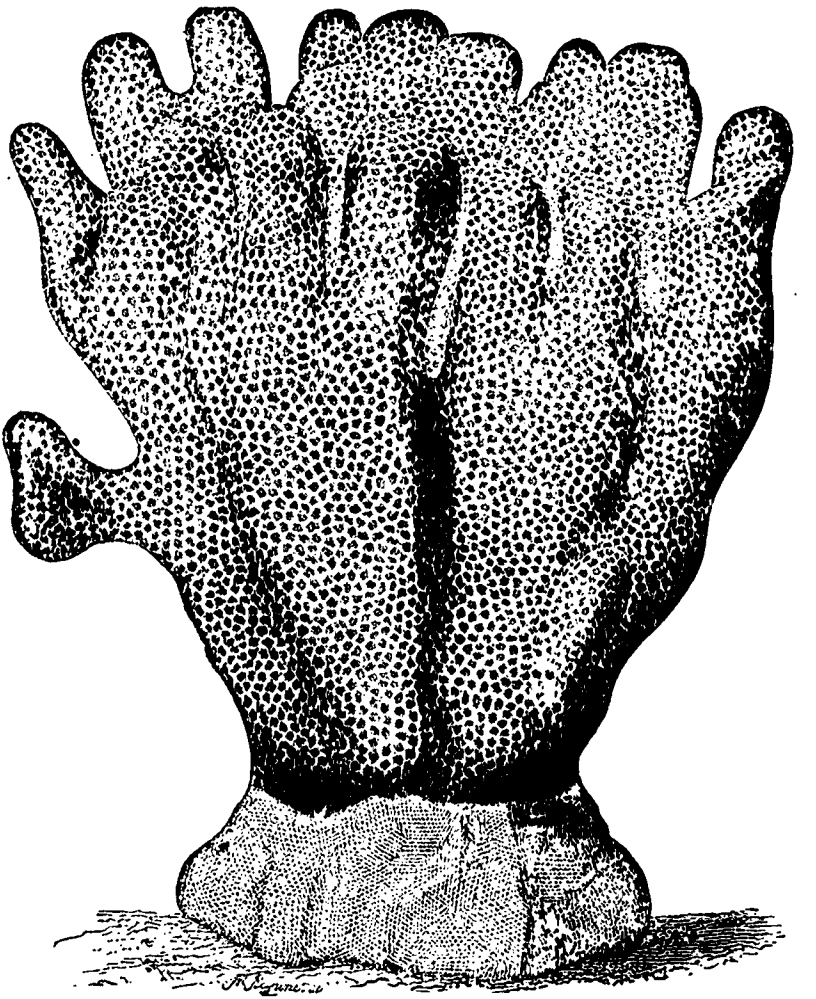
DENDROPHYLLIA NIGRESCENS, D.

the budding cluster. Below a case of this kind is represented, in which the stem is a large column.



GONIOPORA COLUMNA, D.

The polyps, in this beautiful Pacific species, as seen, stand up prominently over the coral when expanded, which is due



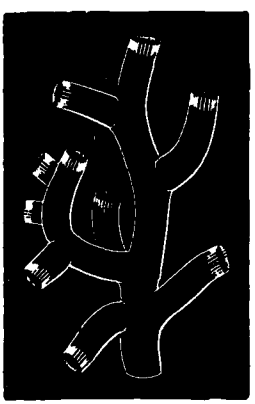
PORITES MORDAX, D.

to the fact that only the lower parts of the polyp secrete coral, as a moment's consideration will make apparent.

In other cases, the budding cluster is small, and hence makes small branches, as in the annexed figure of a species of Porites, from the Feejees. The cells in this genus are very small and nearly or quite superficial, as the figure shows.

New branches are made in such species by a forking of an old one. The budding cluster enlarges as it grows, and, when it is just beginning to pass the regular or normal size for the species, a subdivision of the budding cluster commences at the extremity of the branch. It is a process of spontaneous fission of a branch or stem. In this way the forking in the coral of the figure on page 32 was produced, and also the branching in that on page 33.

Sometimes, again, the budding cluster is a linear series; and then a coral with erect, flattened or lamellar branches is made.

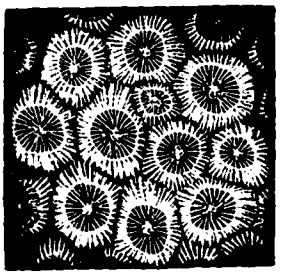


CLADOCORA ARBUSCULA.

Again, sometimes each branch of the corallum is only the corallet of a single polyp; and new branches are added by the budding of new polyps from its sides, each to lengthen out into a new branchlet. In this manner the coral here figured, and many like it, were grown. It is a common species of the West Indies.

When the budding is not confined to any particular polyp, or cluster of polyps, but takes place universally through the growing mass, the coral formed is more or less nearly hemispherical; and often the process goes on with such extreme regularity that these hemispheres are perfectly symmetrical, even when enlarged to a diameter of ten or fifteen feet. A portion of the surface of one of these massive species, called *Orbicella cavernosa*, from the West Indies, is represented in the annexed figure. In the growth of these hemispheres, the enlargement takes place in the spaces between the polyps; and whenever these spaces

begin to exceed the width usual to the species, a new mouth opens, commencing a new polyp; and thus the growth of the mass involves multiplication by buds. The small calicle near the centre of the figure is from one of the new interstitial buds.



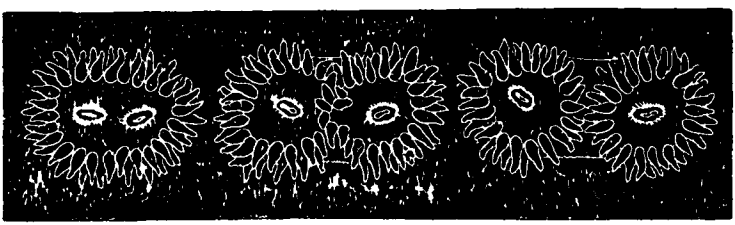
ORBICELLA CAVERNOSA.

Species of Porites also grow into hemispheres and rude hillock-like forms, through the same method of budding, and some of the masses in the tropical Pacific have a diameter of even twenty feet. Myriads of living polyps are combined in a single such mass, for each is but a fifteenth or a twentieth of an inch in diameter.

Often there is a lateral growth of the polyp and thereby of the zoöphyte without much upward growth; and spreading leaves are thus made, and bowl-like shapes. Where there is lateral budding, the leaves have generally an edge of young polyps from the new buds that are there opening, as in the Gemmipores, and some foliaceous Madrepores; where there is superior budding, and sometimes in the case of inferior, the new polyps appear some distance from the edge, the growing margin spreading on in advance of the buds that open in it, as in the Echinopores.

Besides the method of budding explained in the above remarks, there is also a kind of superior budding called *spontaneous fission*, which consists in a spontaneous subdivision of a polyp, by which two are made out of one. In such cases the disk of the polyp has not a distinct limit of growth, as in the above, but tends to enlarge indefinitely; and when there is a beginning of an increase beyond the proper adult size, a new mouth opens in the disk, a short distance from the old one, and at the same time its edges extend downward and make a new stomach beneath it; finally tentacles are developed between the two mouths, and then each polyp separates with its part of

the old tentacles, as illustrated in the following figure. It is not, as is seen, a subdivision strictly into halves, as one carries off the old mouth and stomach. The figure to the left represents a polyp of the Astræa tribe, with already two mouths, through a commencement of the process of subdivision. In the next figure there are tentacles between the two mouths, so that each



SPONTANEOUS FISSION IN POLYPS.

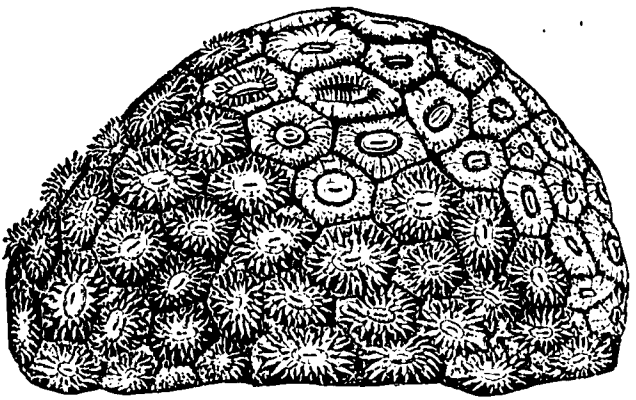
mouth has its own circle; and in the third, the separation has gone so far as to complete the circles and make two independent polyps. This dividing one's self in two, for the sake of an increase of population, is the process called spontaneous fission or fissiparity.

This mode of budding does not belong exclusively to coral polyps, for it has been observed among a few Actiniæ. Gosse describes its occurrence in a British species, the *Anthea cereus*, in which it results in two distinct animals. He says "the fission begins at the margin of the disk, and gradually extends downward until the separation is complete, when each moiety soon closes and forms a perfect animal." The same author alludes to the occurrence of double-disked individuals of the genera Actinoloba, and Actinia as illustrating the process without a separation of the spontaneously developed pair.

This spontaneous fission is the common kind of budding in the large Astræa tribe.

The following figure represents a species of living coral of the Astræa family, from the Feejees, the *Astræa pallida*, D. which grew, and multiplied its polyps as it grew, by this method. In such species some of the disks of the polyps will

be found to have two mouths. This is the first step in the



ASTRÆA PALLIDA, D.

process. In others, the two mouths will be found to be partly divided from one another by new-formed tentacles; and finally each will have its own circle complete and all else in polyp perfection.



CAULASTRÆA FURCATA, D.

Many of the Astræa hemispheres of the Pacific, grown by this method, have a diameter of ten to fifteen feet.

In other Astræa-like species, this spontaneous fission ends in a complete separation of the two polyps formed; and consequently in a forking of an old branch. The figure annexed, of a Caulastræa, from the Feejees, illustrates

this mode of branching. In the left-hand polyp there are already two mouths, and the work of subdivision is consequently begun; while in those to the right, which have a single mouth, the subdivision has just been completed, and also the forking of the old branch. Thus spontaneous fission goes forward, and branches accordingly multiply. By this method some of the most magnificent clumps of coral zoöphytes found in tropical seas have been, and are being, developed each from a single germ. Many of them have the perfect hemispherical symmetry of the solid Astræas.

Sometimes, when a new mouth forms in an enlarging disk, there is not at once a separation of the two, but the disk continues to enlarge in one direction and another, and then another mouth opens, and so on until a string of mouths exists in one elongated disk; and finally, a separation occurs, but only to commence or carry forward another long series. In this way the corals with meandrine furrows are made, some kinds of which are popularly called "Brain coral," and pertain to the Meandrina family (figure on page 44). The same may take place in the ramose corals, and so make flat branches, each with a long sinuous line of polyp mouths at top. In all such species the tentacles stand in a line either side of the line of mouths.

By the simple methods here explained all of the various forms of Actinoid zoöphytes have been produced; and, equally so, those of the Alcyonoids described beyond. The tree, shrub, clusters of coral leaves, hemispheres, and coral net-work require for the explanation of their origin only the few principles which have been mentioned. The germ-polyp, growing upward and more or less outward, and budding as it grows, makes thus the rising stem—that of the Madrepore or Dendrophyllia, with its summit polyp (figures p. 29, 31), or that of the Porites, with its terminal budding clusters (p. 33); or the rising, massive dome of the Astræa and Mæandrina (pp. 37, 44), in case budding is symmetrical in all directions;—or, if growth in the germ-polyp is upward exclusively, it forms a rising stem bearing at top the single polyp that originated it,

or crowded clusters of such stems branching variously and having each branch surmounted with its one polyp (figure p. 32); or, if there is lateral growth and but little of upward, it produces leaf-like forms and graceful groups or clusters of leaves, vases, and other shapes; or, if the germ-polyp is capable of lateral growth alone, the results are simple lines of polyps creeping over the supporting rock, like the creeping stolons of a plant, or else encrusting plates, spreading outward like a lichen.

In the descriptions of corals the following terms have the significations annexed. Those already mentioned are here repeated to bring them all together.

Zoöthome.—The compound animal mass produced by budding.

Corallum.—The coral either of the compound mass, or of the solitary polyp.

Corallet (in Latin, corallulum).—The coral of a single polyp in a compound corallum.

Calicle.—The polyp cell in the top of a corallet, or of a solitary corallum, within the walls of the cells; it is sometimes flat at top, that is, without the usual depression.

Septa.—The radiated plates of the cell or calicle.

Dissepiments.—Small cross plates between adjoining septa (sometimes wanting).

Synapticulæ.—Minute cross bars uniting the surfaces of adjoining septa.

Cœnenchyma.—The common mass of the corallum between its different polyp cells or corallets, as in the Madreporæ, Gemmiporæ and Dendrophylliæ.

Epitheca.—The coral layer sometimes deposited over the exterior of the corallum during the life of the polyp by the outer skin before it dries away, as explained on page 25.

Peritheca.—The epitheca of a compound group or zoöthome (fig. p. 50).

Exotheca.—The portion of the corallum outside of the walls of cells in many coralla of the Astræa family, and some others, in which the polyps of the mass are properly in contact, and there is consequently no true cœnenchyma.

Endotheca.—The portion of the corallum inside of the walls of the cell.

We may now state briefly the characteristics of the grander divisions of the Actinoid polyps, several of which have been illustrated in the preceding figures.

The tribes adopted are those recognized by Prof. Verrill, and have the limits he has assigned to them. The classification

diverges from his system in uniting the non-coral making and coral-making species into one grand division, that of the Actinoids (on the ground of the close resemblance of the polyps), and also in separating from the latter the Cyathophylloid corals, for the reasons mentioned on page 5. Some of the figures of corals on former pages are here repeated in order to present together those of like relations.

1. *Species without internal Coral Secretions.* ACTINARIA of Verrill.

1. The *Actinia tribe*, or ACTINACEA, secrete no coral internally, and moreover have a muscular base, with some degree of locomotion by means of it. The Actiniæ of the frontispiece, and of pages 6, 9, are examples.

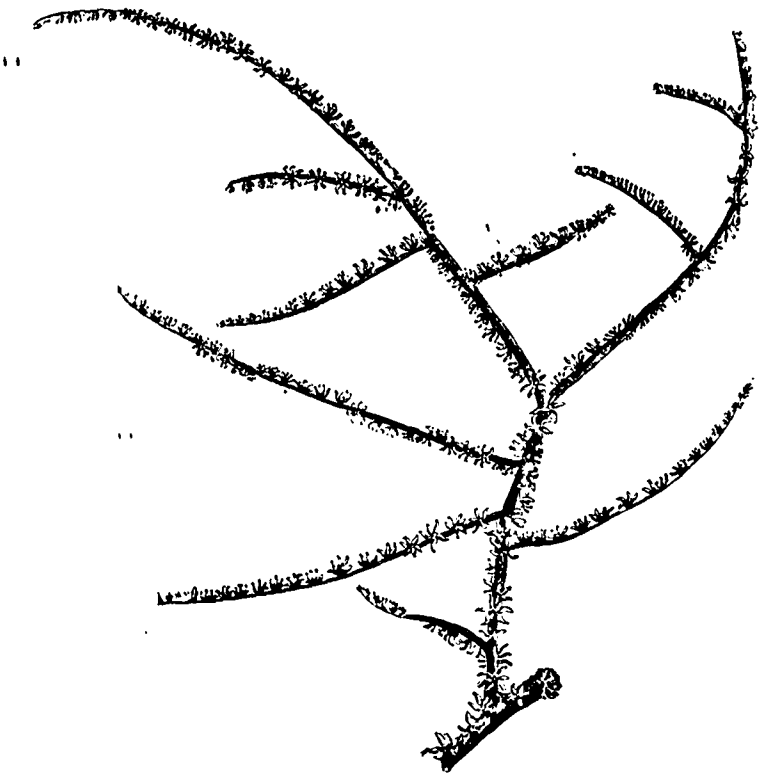
2. The *Zoanthus tribe*, or ZOANTHACEA. The species here included are like the Actiniæ in secreting no coral. But while they have a base, it is not muscular, and they are never capable of locomotion. The polyps have a thick or somewhat lea-



EPIZOANTHUS AMERICANUS, V., WITH EUPAGURUS PUBESCENS, ST.

thery exterior, and, as already observed (p. 19), have gills, or branchiæ. Some of the species are solitary polyps; but generally they form compound masses or zoöthomes, by budding; sometimes making simple lines of polyps over a supporting surface; at other times incrusting plates, or irregular masses. The preceding figure (from Verrill) represents a species found in American seas off the coast of New Jersey, in deep water, and also in Massachusetts Bay, which has a habit of fixing on a shell for its support and of always taking one containing a

soldier crab. The shell finally becomes dissolved away—how, it is not known—by the growing Zoanthid ; but the crab holds on to its house, although at the expense of transporting wherever it goes a colony of flowering polyps. The polyps are but partly expanded in figure 1, and wholly so in figure 2.



ANTIPATHES ARBOREA, D.

The animals of the Zoanthus tribe have broad, radiated disks, with an edging of shoft tentacles, in one or more rows. Although not secreting coral, the mucus of the surface in some

of the species entangles the sand that falls on it, and thus gives a degree of firmness to the mass of the zoöphyte.

3. The *Antipathus tribe*, or ANTIPATHACEA. In this tribe the polyps never have locomotion, and, as far as known, always produce compound groups by budding. These groups have the forms of delicate shrubs and long twigs; and some of them are three feet or more in height. The branches consist of a horny axis, usually spiny or hispid over its surface, surrounded by an animal coating, which is made up of united polyps. An example is shown in the following figure of a living species from the Feejees. A view of one of the polyps, much enlarged, is given in the following figure. Its tentacles are closely like those of the Actinia. The height of the entire



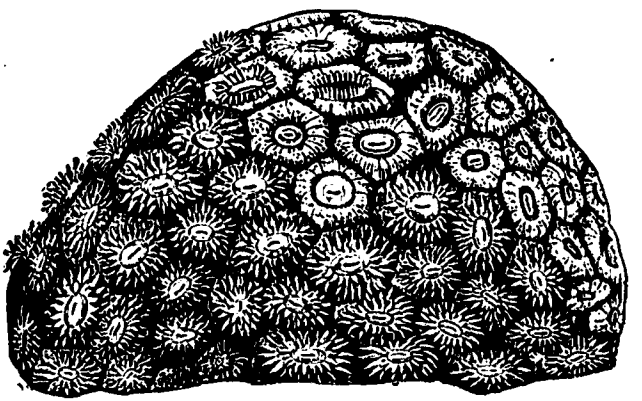
POLYP OF A. ARBOREA, MUCH ENLARGED.

shrub, collected by the author, was three feet, and the trunk at base was half an inch thick. The polyps had a brownish-yellow colour, not particularly beautiful, and the tentacles were in general, as in another species described by the author, rather awkwardly handled by the polyp. The number is commonly *six;* but in one genus, Gerardia, it is as great as *twenty-four*.

2. *Polyps having internal calcareous secretions.* MADREPORARIA of Verrill. (*The Cyathophylloid species excluded*).

4. *Astræa tribe*, or ASTRÆACEA.—In this tribe the polyp-cells or calicles are distinctly lamello-radiate within, and generally so outside. Moreover, budding is always by division of the disks, or spontaneous fission. The figure of the Caulastræa, on

page 37, illustrates one section of this family, that in which each branch of the corallum is made by a single polyp, and branching is by furcation through spontaneous fission. In other related genera, as Mussa, the polyps sometimes have a diameter of two inches, being as large as ordinary Actiniæ.



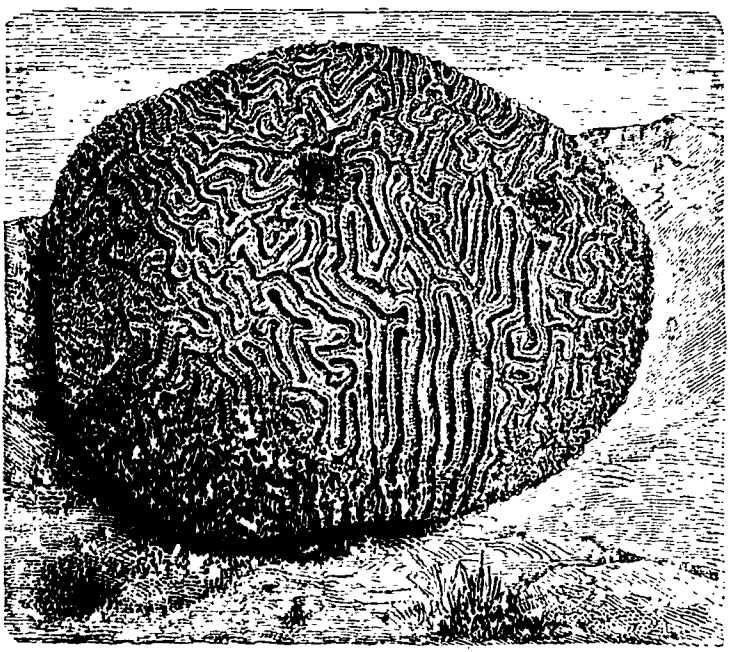
ASTRÆA PALLIDA, D.

The *Astræa pallida* is a good representative of the massive Astræas. The colour of the polyps in this species is quite pale, the disks being bluish-gray, and the tentacles whitish. In others, the tentacles are emerald-green, or deep purple, or of other shades.

Another range of forms is represented by the following figure of one of the Meandrine corals, already referred to as often called "Brain coral." In the figure, the coral is reduced one-half lineally. The difference between its mode of formation and that of an Astræa has been stated on page 38. This species is common at the Bermudas, where it grows to a diameter of three feet. It is also found in the West Indies. The ridges in this species are double, and hence the name *Diploria*, from the Greek for *double*. A common large West India species of Brain coral is called *Meandrina labyrinthica*.

It is readily distinguished from the Diploria by the ridges between the furrows, these being simple and triangular.

Still other forms of the Astræa tribe are foliaceous, or such as would result if the growing margin of an Astræa, or of a Meandrina, were to spread out into folia instead of thickening

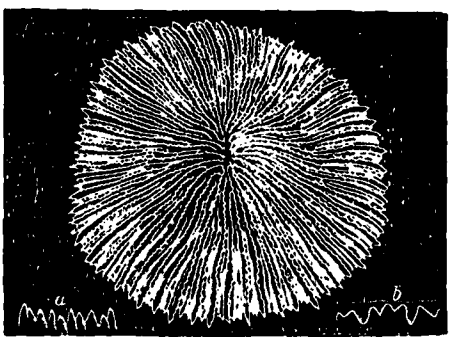


DIPLORIA CEREBRIFORMIS, E. AND H.

upward in the ordinary way. The groups of gracefully curving leaves thus made are sometimes very large and symmetrical.

2. *Fungia tribe*, or FUNGACEA.—The general character of the simple species of this tribe is mentioned on page 25, and the character of the living Fungia, with its tentacles, is shown in the figure of a Feejee species on page 26. The corallum of another large species, the *Fungia Danæ*, is represented

in the annexed figure one-sixth the actual diameter. Large, compound groups, both massive and foliaceous, are formed by budding, and the budding is always superior. There are no margins to the disk in this tribe, and in the corallum of

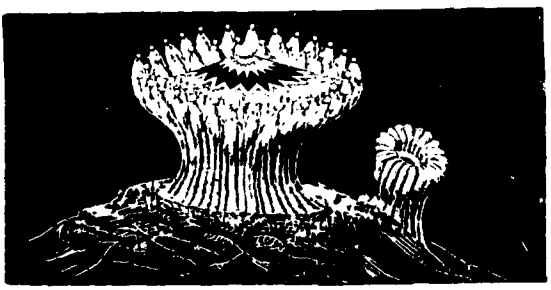


FUNGIA DANÆ, E. & H., REDUCED TO ONE-SIXTH LINEALLY: *a*, *b*, TEETH OF UPPER AND LOWER MARGINS OF SEPTUM, NATURAL SIZE.

the compound kinds no wall or partition between the adjacent stars, and no walls to adjoining polyps, or only imperfect ones. The polyps consequently coalesce throughout by their disks. The simple Fungiæ are attached when young, and then would hardly be distinguished from a simple or solitary species of the Astræa tribe.

3. *Oculina tribe*, or OCULINACEA.—These species occur either simple or compound, and the latter are often branched, massive, or encrusting, never thin, foliaceous. Budding is either superior, lateral, or basal; never by spontaneous fission. The coralla are remarkable for the solid walls and lamellæ of the cells; and often for having the cœnenchyma nearly or quite solid. Transverse septa between the lamellæ are sometimes wanting. The calicles are usually striated externally, but seldom dentate. The polyps, moreover, are small; and very commonly they stand prominent above the corallum when expanded. The Orbicella, figured on page 35, is an example of one of the massive Astræa-like forms, constituting the Orbicella family, or *Orbicellidæ*, in the Oculina tribe.

The Caryophyllia here figured is one of the solitary species of the tribe found in European Seas, and on the coast of Great Britain. The figure is from Gosse's "British Actinology." It also grows much longer in proportion to the breadth. The



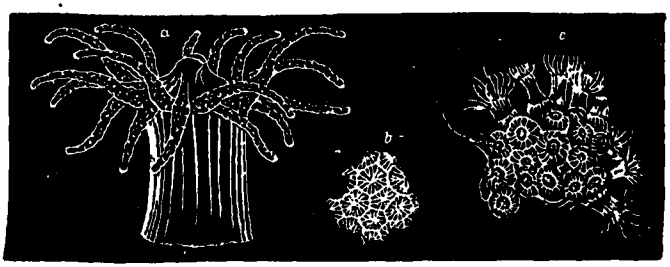
CARYOPHYLLIA SMITHII, STOKES.

figure to the right is of one unexpanded. One of its lasso-cells, in different states, is shown in figures 3, 4, 5, on page 13.

The corallum of a related species is given on page 22. The walls and septa are remarkably solid. This species, the *Caryophyllia cyathus*, has been found not only in the Mediterranean, but also at the Azores. Another species, the *C. clavus*, has a wide distribution, occurring in deep water in the Florida straits and off the British coasts as well as in the Mediterranean.

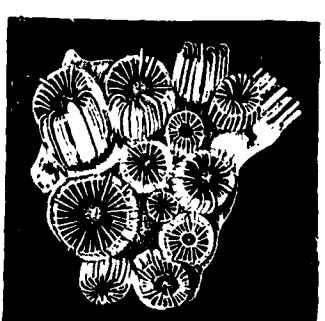
Another example of this tribe, as defined by Professor Verrill, is the species of Astrangia occurring alive along the southern shores of New England, and on the coast of New Jersey. Specimens are not uncommon in the vicinity of New Haven, on the rocks by the Light-House, and at other places in Long Island Sound, and when alive it is an exceedingly beautiful object. The accompanying figures of the animal are from the drawings made to illustrate a yet unpublished memoir by Professor Agassiz. They are copied from the "Sea-Side Studies" of Mrs. Agassiz and Alexander Agassiz. In figure

c, the polyps are of the natural size, while figure *a* represents one of them enlarged, The polyps, as is observed, stand very prominent above the cells of the corallum, because only the bases of them secrete coral; and the buds, which open between the calicles, are hence *lateral* buds; the coral has much resemblance to that of an Orbicella, in which budding is marginal.



ASTRANGIA DANÆ, AG.

The tentacles have minute warty prominences over them, which are full of lasso-cells, each about a 500th of an inch in length, or about two-thirds larger than those of the *white cords* that edge the internal septa. The corallum, though massive, is somewhat irregularly lobed above, and grows to a diameter of two or three inches. It is covered with stars an eighth of an inch to a sixth across (figure *b*), which are usually crowded together, the intervening wall being very thin and solid. The author alluded to the crowd of stars in the name Pleiadia, which he proposed for the genus in his Report on Zoöphytes (page 722).



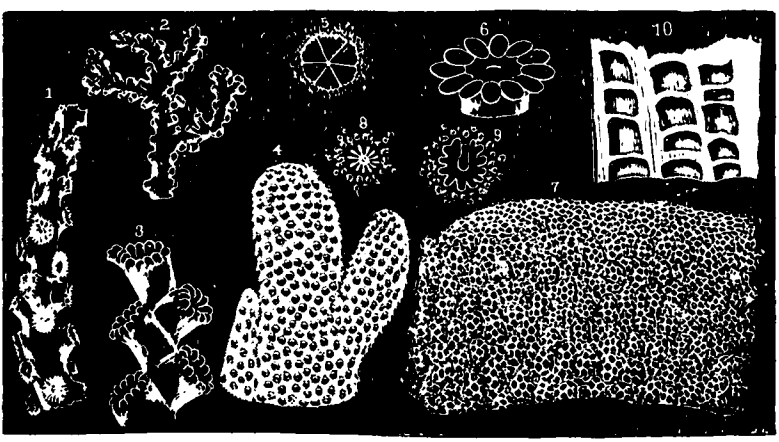
PHYLLANGIA AMERICANA, E. & H.

The genus Cladocora, containing slenderly branching ramose zoöphytes, is closely related in its polyps, according to

Professor Verrill, to the Astrangiæ, and belongs to that family. Its cylindrical stems are gathered into crowded clumps. The *C. arbuscula* is figured on page 34.

A West India species of another genus of the group, the *Phyllangia Americana*, is represented in the preceding figure.

In the following cut, figure 1 represents the extremity of a branch of an Oculina, the *O. varicosa*, of the family *Oculinidæ*. The species of this genus grow in clumps of round branches, and have very solid corolla, so white and firm when bleached



CORALS OF THE OCULINA TRIBE.

as to go by the popular name of "white coral," and to be sometimes polished for beads and other such ornamental purposes.

Figure 2 is a branch of a beautiful little coral called *Stylaster erubescens* Pourt., and 3, a portion of the same enlarged. It has the firmness, and something of the habit of an Oculina, but is rather like a miniature Oculina, its calicles never exceeding a twentieth of an inch in breadth. There are a number of genera in this Stylaster family, the *Stylasteridæ*, and the corals are among the most delicate of species.

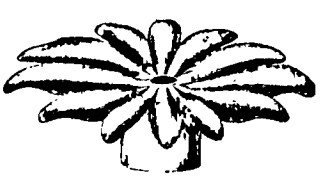
Figure 4, in the same cut, represents a portion of a branch of the *Stylophora Danæ* E. and H. The corals of the genus are remarkable for their small, crowded calicles, and for the very distinct six-rayed star in each calicle (as shown magnified in figure 5), and usually have a prominent point or columella at the centre of the star. The polyp of a Feejee species, *S. mordax*, is represented in figure 6. The name of the family, *Stylophoridæ* (signifying style-bearer), alludes to this columella. The corals grow in regular hemispherical clumps consisting of flattened or rounded branches, and are sometimes a foot or more across.

In another family under this tribe, the *Pocilliporidæ*, very common in coral-reef seas, the cells of the corallum are always very small and crowded, as shown in figure 7. The corals are branching, and in Pocillipora, the surface is often irregular and warty, the little prominences, like the rest, being covered with polyp cells; while in Seriatopora, the branches are slender, even, and pointed. The corallum in both is very firm and solid. In the larger part of them the number of tentacles is only twelve, and formerly they were referred on this account to the Madrepore tribe; a few have as many as twenty-four tentacles.

The Pocilliporæ form hemispherical clumps like the Stylophoræ; and the branches vary from the flattened and broad form shown in figure 7 (which represents the upper part of a branch of the *P. grandis* D.), to irregularly cylindrical branches, looking rough on account of the very short branchlets. The cells are usually stellate, as in figure 8, from *P. elongata* D., and often one of the septa, and sometimes two opposite ones, extend to a columella at the centre, as illustrated in figure 9, from *P. plicata* D.; dividing the cell into halves. The cell in the interior of the corallum is crossed by thin plates or tables, as shown in figure 10, and hence they have been called *tabulate* corals. Agassiz, after the discovery of the Hydroid character of the animals of the Millepore corals, whose cells also are tabulate, referred the Pocilliporæ to the same Hydroid type. But recent study of the polyps has shown that they are

true polyps; and Professor Verrill remarks on the resemblance of the tentacles to those of the Oculinæ. The stellate character of the calicle also proves that the animals must be polyps.

Madrepore tribe, or MADREPORACEA.—In this tribe the coralla, even to the walls of the corallets, are remarkable for being porous, and the radiating lamellæ of the polyp-cells are narrow, often perforated or imperfectly developed, and frequently mere points. The coralla are either branched, massive, or foliaceous. Budding is lateral, and in the branching species there is either a parent polyp, as in Madrepora and Dendrophyllia, or a terminal budding cluster. This peculiarity has been already illustrated in the figure of *Madrepora aspera*, on page 29. On the following page there is an outline sketch of another species, the *Madrepora formosa* D., common in the Feejees, and also in the East Indies. The two species here mentioned give a good idea of the ordinary character of the Madrepore corals. One of the polyps of the *Madrepora cribripora* D., a species collected in the Feejees, is represented much enlarged in the accompanying figure. The natural size of the expanded polyp in this genus is generally from an



POLYP OF M. CRIBRIPORA, D.

eighth to a twelfth of an inch across the star. The disk of the polyp is quite small, and the number of tentacles is always twelve. The most common colour of the polyps is green, while that of the general surface between is ordinarily a pale or a dark umber. In many species of Madrepora the branches spread out laterally from a central or lateral trunk, and coalesce together into a complete net-work, having the form of a shallow vase; and the interior of the vase is filled with multitudes of short, cylindrical coral stems, rising from the reticulating



MADREPORA FORMOSA.

branches, which, when alive, have literally the aspect of sprigs of flowers in the vase.

In certain kinds, closely related to Madreporæ, the calicles are reduced to points, or spiniform or angular prominences, or fail altogether, and there are sometimes rounded prominences between the cells; these degraded Madrepores belong to the genus Montipora (Manopora of the Author's Report).

The genus Dendrophyllia is also referred to the Madrepore tribe. The budding, as already explained, is of the same kind as in the Madrepores. But the tentacles exceed twelve.

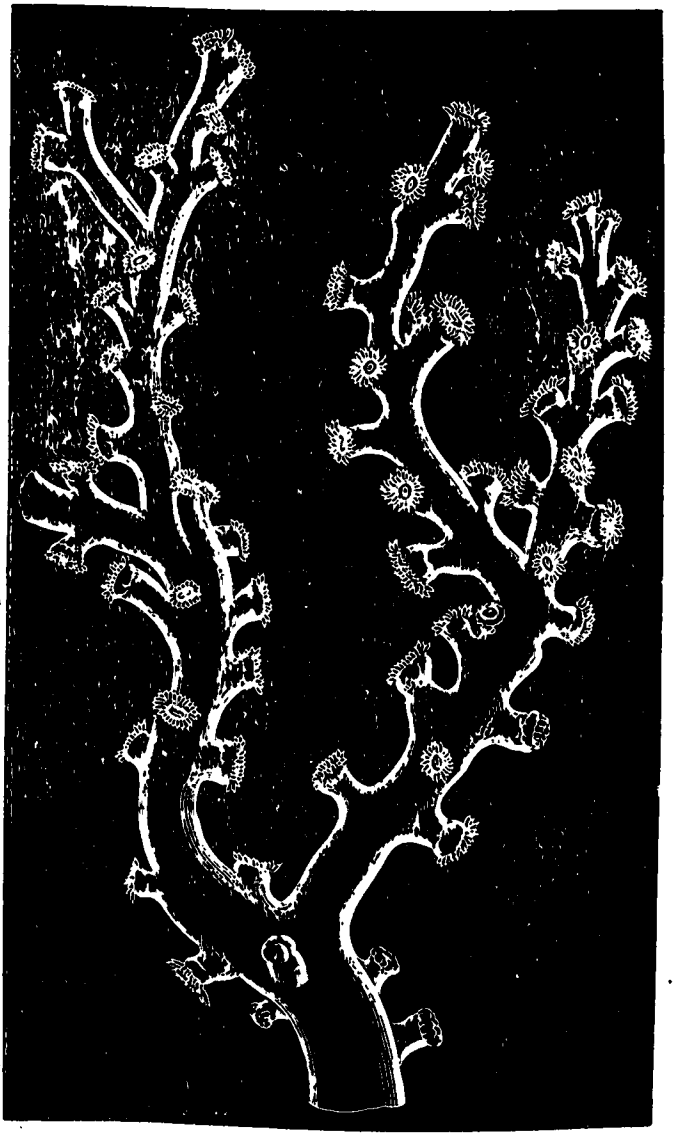


POLYP OF DENDROPHYLLIA NIGRESCENS.

One of the polyps of *D. nigrescens* D., enlarged, is shown in the accompanying figure. This Pacific species grows to a height of at least three feet, and is peculiar in having a very dark blackish green or almost black colour, while the polyps have the tentacles nearly colourless, and the disk has a circle of emerald green around the mouth. *Dendrophyllia arborea* is the name of a common species of his genus found in deep water in the Mediterranean; it is equally large with the preceding, and somewhat similar in its mode of branching, but a little stouter. It has also been found in the Atlantic about the Azores. Another common Mediterranean species is the *D. cornigera.* It is sparingly branched, and has very long and stout corallets, sometimes as long and large as the finger.

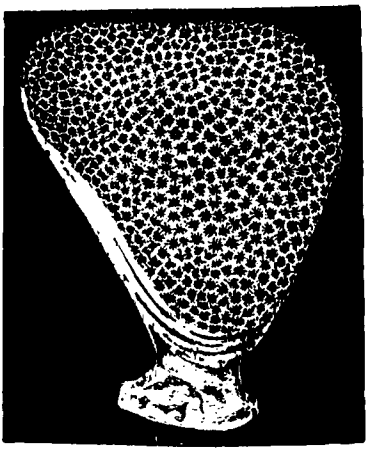
The genus Gemmipora contains porous corals, of foliaceous, bowl-like, and massive forms, covered by prominent cylindrical, porous calicles, and having many short tentacles to the polyps, usually in a single circle.

Here belongs also the large *Porites* family (Poritidæ), the corals of which are very porous, and sometimes almost spongy, and whose polyp-cells are exceedingly shallow, and usually only imperfectly radiated.

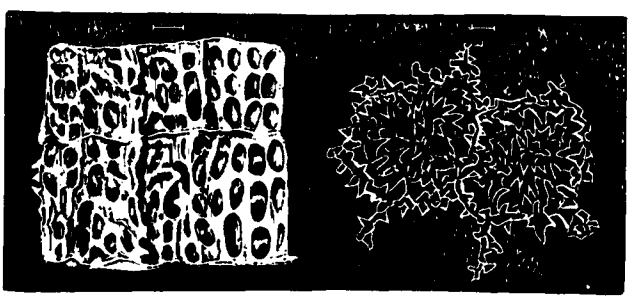


DENDROPHYLLIA NIGRESCENS, D.

One of the genera in this family is Alveopora. It contains the lightest of known corals, the texture being exceedingly porous, and the walls of the cells, which are continued regularly through the corallum, are like delicate lace-work. As stated long since by the author, "they are intermediate in character between the Montiporæ and the Favosites group"—as shown by the texture and the horizontal partitions across the cells, giving them the "tabulate" character of the ancient Favosites, as represented by the author in the annexed figure exhibiting a section of the corallum of a Feejee species. On account of this tabulate structure,



ALVEOPORA VERRILLIANA, D.



VERTICAL SECTION OF CORALLUM, AND UPPER VIEW OF CALICLES, ENLARGED, OF ALVEOPORA SPONGIOSA, D.

the genus was referred by the author to the Favosites family. A related species, of unknown locality, has been made the

type of a new genus, called *Favositipora*, by Mr. W. S. Kent, on the ground of its tabulate character (Ann. Mag. Nat. Hist., 1870), thus confirming, though overlooking, the author's conclusions.

In the genus Porites, the corals are frequently branching, as in the *Porites mordax* D., sometimes more slenderly, but oftener less so, and at times massive and monticulose in form. Another species of Porites is represented on the following page, with one of the branches fully expanded, but the others in outline; a polyp, much enlarged, having twelve tentacles as in the Madreporæ, is shown in the accompanying figure. The cells of the corallum are superficial, and hence the name of the species, *Porites levis*.

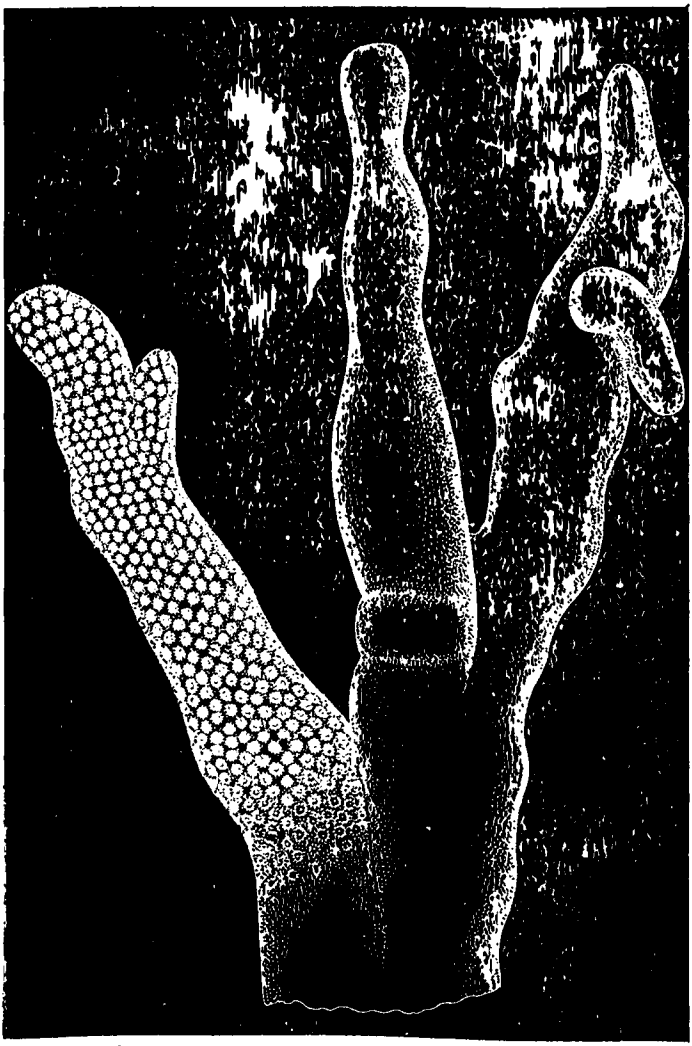


POLYP OF PORITES LEVIS.

Another form, different in the size and character of its polyps, is exemplified in the genus Goniopora. In the species figured on page 32, the colour of the projecting polyps was lilac or pale purple, and the number of tentacles eighteen to twenty-four, yet all were in a single series. The columns grow to a height of two feet or more, with only the summits for two or three inches alive. The dead portion is usually encrusted with nullipores, sponges, serpulæ and various shells, which protect the very porous corallum within from wear and solution by the moving waters.

II. CYATHOPHYLLOIDS.

It is not necessary to dwell here at length upon the ancient Cyathophylloids. The corals have a close resemblance to those of the Astræa tribe in general aspect, varieties of form, and range of size; the methods of multiplication by buds were the same that are now known in the Oculina tribe. Some of the larger kinds of simple corals, such as those of the genera Zaphrentis and Heliophyllum, had at times a diameter of three or four inches, so that the breadth of the polyp flower was probably at least six inches. Hemispherical masses of solid



PORITES LEVIS, D.

corals attained, in some species, a diameter of several feet. No doubt the colours, among the coral polyps and other life of the ancient seas, were as brilliant as now exist.

Nature's economist here puts the question—Why all this beauty when there were no eyes to enjoy it? But beauty exists because, "in the beginning," "the Spirit of God moved upon the face of the waters;" and man finds delight therein inasmuch as he bears the image of his Maker.

A single recent species has been obtained by Mr. L. F. de Pourtales, in dredging at a depth of 324 fathoms, near the Florida reef, which may be a Cyathophylloid, although it has been supposed that the species of the tribe have been extinct since the middle of the Mesozoic era. It was half an inch high and broad, and the polyp-cell had eight septa—*a multiple of four*, as in the true Cyathophylloids. The discoverer has named it *Haplophyllia paradoxa*. But he observes that it may after all be only an abnormal Actinoid.

III. ALCYONOID POLYPS.

The name *Alcyonium*, given to some of the species of this group, is derived from Alcyone, the fabled daughter of Neptune. It is sometimes written with an initial H, in conformity with the aspirate of the Greek word; but Latin authors usually omitted the H, and this has been good enough authority for Linnæus and the majority of later writers.

The Alcyonoids include some of the gayest and most delicate of coral shrubs. Almost all are flexible, and wave with the motion of the waters. They contribute but little to the material of coral reefs, but add largely to the beauties of the coral landscape. Not only are the polyps of handsome tints, but the whole shrub is usually of a brilliant orange, yellow, scarlet, crimson or purple shade. Dun colours also occur, as ash-grey, and dark brown, and almost black. Some kinds, the Sponggodiæ, are too flexible to stand erect, and they hang from the coral ledges, or in the coral caves, in gorgeous clusters of scarlet, yellow, and crimson colours.

The species of this order spread from the tropics through the colder seas of the globe, and occur at various depths, down to thousands of feet.

The two following are the most striking external peculiarities of the polyps: the number of tentacles is always eight; and these tentacles are always fringed with papillæ, though the papillæ are sometimes mere warts. Some of the various forms of the polyps are shown in the figures on the following pages.

But besides these characteristics, there is also the following: the existence of only eight internal septa, and these septa *not in pairs;* consequently, the interior is divided into only eight compartments (octants), and with each a tentacle is connected. Hence in the Alcyonoids, as Prof. Verrill has observed, the areas externally, and the compartments within, are all *ambulacral*, or tentacular, which makes a wide distinction between them and the Actinoids (p. 11) in which only the alternate are tentacular.

The solid secretions of these polyps are of two kinds: Either (1), internal and calcareous; or (2), epidermic, from the base of the polyp. The latter make an axis to the stem or branch, which is either horny (like that in Antipathus, p. 42) or calcareous. A few species have no solid secretions.

All the species are incapable of locomotion on the base; yet there are some that sometimes occur floating in the open ocean.

The three following divisions of the Alcyonoids are those now generally recognized :—

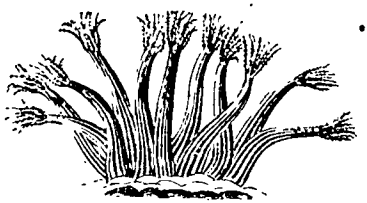
1. The *Alcyonium tribe*, or ALCYONACEA.—One of the forms under this tribe is represented in the annexed figure. It is from the Feejees (like most of the zoöphytes figured by the author), and in the living state the polyps had the middle portion of the tentacles pale brown, with the fringe deep brown. In another more beautiful species of the genus, from the same region, the *Xenia florida* D. (made *Xenia Danæ* by Verrill, as it proved to be distinct from Lamarck's species to which the author referred it), the polyps are as large, but shorter, and the colour is a shade of lilac. These species differ from the larger

part of the Alcyonia in having the polyps not retractile; the tentacles fold together, if the zoöphyte is disturbed, but cannot hide themselves.



The following figure represents another related species obtained by Dr. W. Stimpson, near Hong Kong, and called by its discoverer *Anthelia lineata;* the polyps are but partly expanded.

Other Alcyonoids are much branched, with the branches thick and finger-like, and soft or flexible, and the polyps small and wholly retractile into the mass. The branches, bare of polyps, are usually of some dull pale colour, and on account of this fact some of these Alcyonia go by the common name of *dead-men's fingers*.

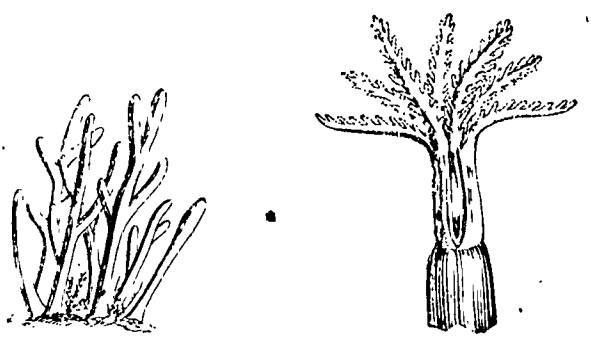


ANTHELIA LINEATA, St.

Some of the species form thick-lobed plates over the rocks; and occasionally they are brightly coloured, even when the polyps are unexpanded.

The above kinds secrete granules or spicules of carbonate of lime in the tissues, and are harsher or softer in texture according to the proportion of these granules.

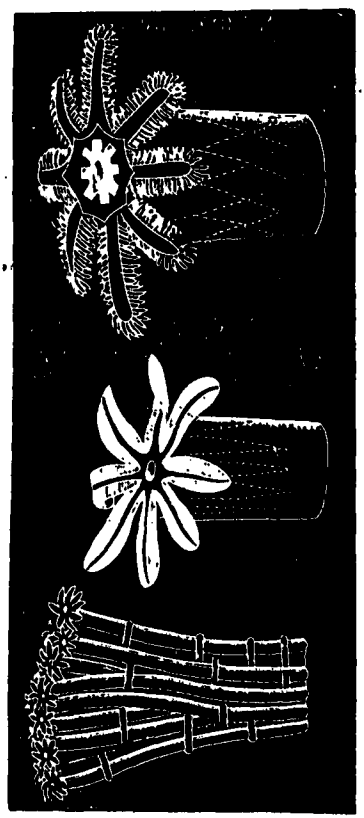
Some species form branching tubes, rising from an incrusting base, which are rather firm owing to the calcareous spicules present. Such species are referred to the genus Telesto—one



TELESTO RAMICULOSA, V.

of which, from Hong Kong, from the collection made by Dr. Stimpson, is here figured (from Verrill). The second figure shows the form of the expanded polyps. The unbranched species of this kind make up the genus Cornularia.

In one family of this tribe the polyps form red calcareous tubes; sometimes a slender, creeping tube, with polyps at intervals, as in a species referred by the author to the genus Aulopora; but generally vertical tubes, grouped into large red masses, called, popularly, *Organ-pipe coral.* A portion of one of the latter—*Tubipora syringa* D.—is represented in the first of the annexed figures, with its expanded polyps; and a polyp from the group much enlarged in the second figure. The papillæ of the fringe are arranged closely together in a plane, so that it is not at first apparent that there is a fringe. The third figure represents, enlarged, the polyp of another Feejee species, the *Tubipora fimbriata* D. Such coral masses are sometimes a foot or more in diameter, and the living zoöphyte, with its lilac or purple polyps fully expanded, looks much like a large cluster of flowers from a lilac bush. The tubes are united by cross plates at intervals.



TUBIPORA SYRINGA, D., AND T. FIMBRIATA, D.

2. *Gorgonia. tribe,* or GORGONACEA.—The following figure represents a species of this tribe from the Kingsmill or Gilbert Islands. It is one of the net-like or reticulated species, the

reticulation being a result of the coalescence of the branchlets. The general colour of the species was crimson; but when alive and expanded it was covered throughout with yellowish polyps



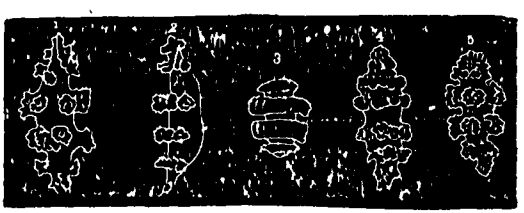
GORGONIA ? FLEXUOSA, D.

of the form in figure *a*, though much smaller, the natural size not exceeding a twelfth of an inch. The common sea-fan of the West Indies, *Gorgonia flabellum*, is much more finely reticulated, the meshes of the net-work being ordinarily not over

a fourth of an inch in breadth; while the fan often grows to a height and breadth of a yard.

Other species of the Gorgonia family are like clusters of slender twigs, and others like many-branched shrubs or miniature trees.

The exterior of the stem or branch in a Gorgonia is a layer of united polpys, with minute calcareous spicules distributed through the tissues and giving the layer some firmness. It is like a bark to the axis of the stem or branch, and may be peeled off without difficulty, and hence is often called the *cortex*. The outer surface of the dried cortex is often smooth, or nearly so; but sometimes covered with small prominences. Over it there may be seen numerous oblong points (one to each of the prominences if there are any); each of these is the spot where a polyp opened out its tentacles when the zoöphyte was alive.



SPICULES OF GORGONIÆ, MUCH ENLARGED.

Kölliker and others have shown that genera, and sometimes species, of the Gorgonacea, may be distinguished by the forms of the calcareous spicules. Some of these knobby spicules are represented in the annexed cut, from figures published by Professor Verrill. The most common forms are those of figures 1, 4, 5; they occur, with small differences, in the genera Gorgonia, Eugorgia, Leptogorgia, etc. Figure 1 is from the *Leptogorgia eximia* V. Figure 2, in which one side is smooth (from the *Gorgonia quercifolia* V), is characteristic of the genus Gorgonia, but occurs in the species along with forms much like figure 1. The forms represented in figures

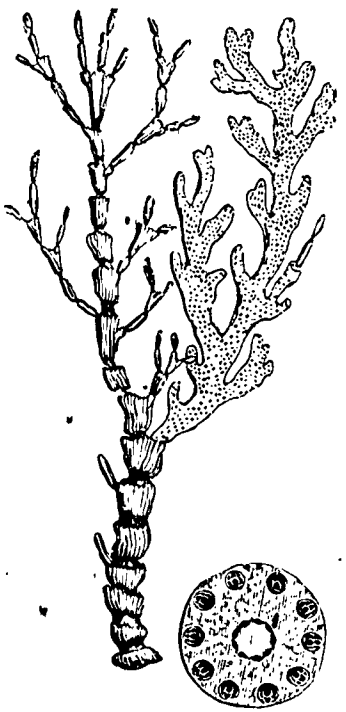
3, 4, 5, are all from *Eugorgia aurantiaca* V., the peculiar kind shown in figure 3 occurring with the other more common form, in species of this genus. In species of Plexaurella many of the spicules are beautiful crosses of various fancy shapes. In Eunicellæ the cortex is covered with an outside layer, in which the spicules are club-shaped, though ornately so, and have the smaller end pointed inward. These spicules afford valuable distinguishing characters also in all Alcyonoids.

The spicules are often brilliantly coloured, and sometimes variously so in the same individual. Yellow, crimson, scarlet, and purple are common colours, and they occur both of dark and pale shades. Viewed under a compound microscope by transmitted light, a group of these spicules from some species, part bright yellow and part crimson, or of some other tints, produces an exceedingly beautiful effect. It gives still greater interest to this subject that all Gorgoniæ owe the various colours they present to the colours of their spicules.

Spicules are usually wholly internal, or they only come to the surface so as to make the exterior slightly harsh. But in other cases, as in the genus Muricæa, they project and give a somewhat bristly look to the coral.

The calcareous spicules are internal secretions, like those of ordinary coral, and the constitution is the same,—mere carbonate of lime. But the secretion of the axis of the branches is *epidermic*, from the inner surface of the cortex, as in the Antipathus before described (page 42). In the ordinary Alcyonoids that make no horny axis, the stolons, or budding stem or mass, creeps or spreads over the supporting body. But in these Gorgoniæ, the budding cluster, which would make a stolon if there were no horny secretions, has the form of a tube about a horny axis; and as this tube elongates and secretes the axis within, it gives out buds externally; thus the branch rises. New branches commence at intervals over the sides of the rising stem or branch through the starting of new budding centres, and so, finally, the Gorgonia zoöphyte is completed.

In a few species, the axis is partly or wholly calcareous. In the Isis family, it is made up of a series of nodes and internodes. The former, in the genus Isis, are white, calcareous, furrowed or fluted pieces; and the latter are smaller and horn-

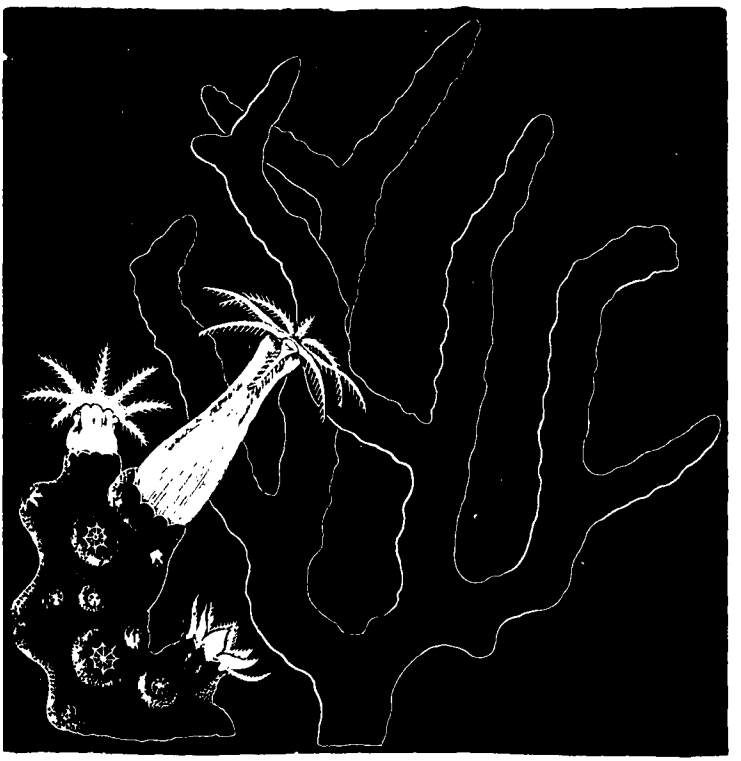


ISIS HIPPURIS.

like in nature, as illustrated in the preceding figures. In the branching stem here figured, the main stem and the branch on the left are simply the axis, bare of the polyp-layer or cortex; while the branch on the right, with the surface dotted, has the cortex complete, and the dots are the sites of the contracted polyps. The circular figure below is a transverse sec-

tion of the stem enlarged, showing the cavities occupied by the retracted polyps.

In the genus Melitæa, and some others related, the internodes are porous and somewhat cork-like or suberous instead



CORALLIUM RUBRUM.

of horny. The species of this group are often bright-coloured and much branched, and resemble, in aspect, ordinary Gorgoniæ; but they are very brittle, breaking easily at the internodes.

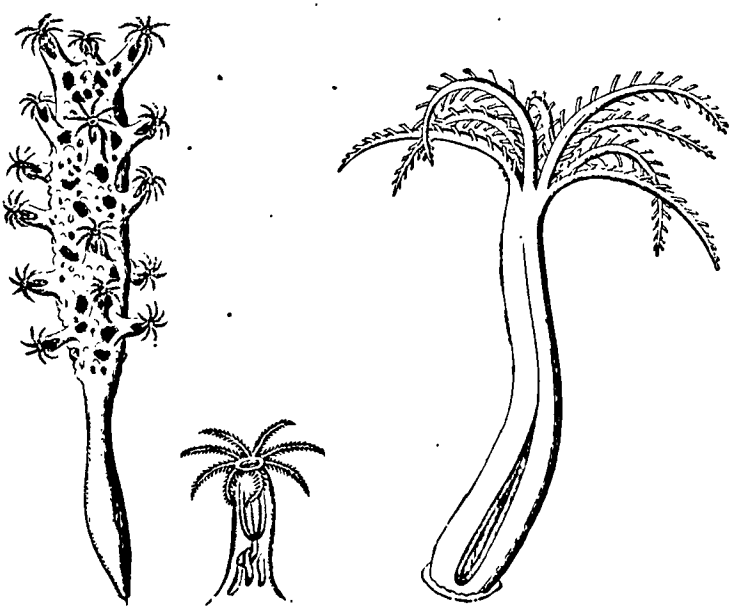
In the Corallidæ, the axis is wholly calcareous, and firm and solid throughout, with usually a red colour, varying from crimson to rose-red. Here belongs the *Corallium rubrum*, or precious coral. The polyp-crust or cortex, which covers the red axis or coral, is thin, and contains comparatively few calcareous spicules, and consequently it readily disappears when the dried specimens are handled. In an uninjured state, the polyp centres may be distinguished over it by a faint six-rayed star. A branch from a specimen obtained by the author at Naples, is represented, of natural size, in the cut on page 66. The polyps, as the enlarged view, by Lacaze Duthiers, shows, are similar to those of other Alcyonoids—the tentacles being eight in number and fringed. The figure represents the extremity of a branch, magnified about four times lineally, with one polyp fully expanded, two partly, and the rest unexpanded. In the living Corallium, they open out thickly over the branches, and make it an exceedingly beautiful object. The coral grows in branching forms, spreading its branches nearly in a plane; and sometimes the little shrub is over a foot in height. The author just mentioned states that, among the polyps, those of the same branch are often all of one sex alone, and that besides males and females, there are a few that combine both sexes.

The precious coral is gathered from the rocky bottom of the borders of the Mediterranean, or its islands, and most abundantly at depths of 25 to 50 feet, though occurring also even down to 1,000 feet. There are important fisheries on the coast of Southern Italy; of the island of Ponza, off the Gulf of Gaeta; of Sicily, especially at Trapani, its western extremity; of Corsica and Sardinia, in the Straits of Bonifacio; of Algeria, south of Sardinia, near Bona, Oran, and other places, which in 1853 afforded 80,000 pounds of coral; and on the coast of Marseilles. The rose-coloured is the most highly valued, because the rarest.

Another species of Corallium was obtained by the author at the Sandwich Islands (Atlas of Zoöphytes, plate 60); but, while probably from the seas of that region, its precise locality is not known.

3. *Pennatula tribe*, or PENNATULACEA. These are compound Alcyonoids, that, instead of being attached to rocks or some firm support, have the base or lower extremity free from polyps and buried in the sand or mud of the sea-bottom, or else live a floating life in the ocean. Their forms are very various.

In the Veretillum family (Veretillidæ) they are stout and short club-shape. One of the species from Hong Kong is



COPHOBELEMNON CLAVATUM, V., AND VERETILLUM STIMPSONI, V.

shown in the figure on the left, with its polyps fully expanded, and the small figure represents one of the polyps enlarged. The third figure represents a polyp of another species, from Hong Kong, a true Veretillum, enlarged three diameters; the specimens, obtained by Dr. Stimpson, and described by Prof.

Verrill, were six to eight inches in length, and, where thickest, were three inches or more in diameter.

A common Mediterranean species is the *Veretillum cynomorium;* and it has been recently found, of a length of ten inches, in the depths of the Atlantic off the coast of Spain. Mr. W. S. Kent observes, with regard to its polyps and their phosphorescent qualities, as follows :—

"Nothing can exceed the beauty of the elegant opaline polyps of this zoöphyte when fully expanded, and clustered like flowers on their orange-coloured stalk ; a beauty, however, almost equalled by night, when, on the slightest irritation, the whole colony glows from one extremity to the other with undulating waves of pale green phosphoric light. A large bucketful of these Alcyonaria was experimentally stirred up one dark evening, and the brilliant luminosity evolved produced a spectacle too brilliant for words to describe. The supporting stem appeared always to be the chief seat of these phosphorescent properties, and from thence the scintillations travelled onward to the bodies of the polyps themselves. Some of the specimens of this magnificent zoöphyte measured as much as ten inches from the proximal to the distal extremity of the supporting stalk, while the individual polyps, when fully exserted, protruded upward of an inch and a half from this inflated stalk, and measured as much as an inch in the diameter of their expanded tentacular discs."

In several genera of the Pennatula tribe there are two kinds of polyps over the surface, and this was the case with the *Veretillum Stimpsoni*, as observed by Professor Verrill. Between the large and well-developed polyps, there were multitudes of small wart-like prominences, each of which proved to be a polyp, but very small and imperfectly developed, having only two lamellæ in the interior instead of the usual eight, and without distinct tentacles, or the ordinary nettling cords within.

Among the other forms of Zoöphytes in the Pennatula tribe are those having a stout axis, with branches either side, arranged regularly in plume-like style (the Pennatulidæ); or a very slender stem and very short lateral polyp-bearing

pinnules or processes along it (the Virgularidæ); or a thin reniform shape (Renillidæ). Others differ from the preceding in having the polyps not retractile; and some of these have a slender stem and the polyps arranged along one side of it (the Pavonaridæ); and still others a terminal cluster of polyps (the Umbellularidæ).

The most of the species secrete a slender, horny axis, and have slender calcareous spicules among the tissues, somewhat like those of the Gorgonidæ.

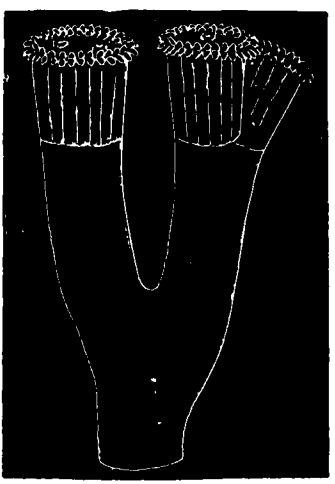
In conclusion, it may here be stated that the reader will find very full illustrations of most of the forms of recent corals, and of their animals, with their natural colours, in the author's Report on Zoöphytes. It is with regret that he has to add, that owing to the special action of the Congressional Committee in charge of the publications of the Wilkes Exploring Expedition, only one hundred copies of this Report were published by the Government, and also of the others of the series, and that but few have been issued besides. The Atlas contains sixty-one folio plates, many of them coloured.

The works on "British Sea Anemones," by Mr. Philip Henry Gosse, contains figures and descriptions of a large number of species, and gives an excellent idea of the most of the forms of Actiniæ, and also presents well their colours. Professor A. E. Verrill has published, in the Memoirs of the Boston Society of Natural History, Vol. I., a "Review of the Polyps of the Eastern Coast of the United States," with a plate illustrating a few of the species.

IV. LIFE AND DEATH IN CONCURRENT PROGRESS IN CORAL ZOÖPHYTES.

The large, massive forms of stony corals would not exist, and the tree-shaped and other kinds would be of diminutive size, were it not for the fact that, in the living zoöphyte, death and life are going on together, *pari passu*. This condition of growth is favoured by the coral secretions; for these give a

chance for the polyp to mount upward on the coral, as it lengthens it by secretions at the top. But, to be successful in this ascending process, either the polyp must have the power of indefinite elongation, or it must desert the lower part of the corallum as growth goes forward; and this last is what happens. In some instances, a polyp, but a fourth of an inch long, or even shorter, is finally found at the top of a stem many inches in height. The following figure represents a case of this kind; for all is dead coral, excepting less than an inch at the extremity of each branch. The tissues that once filled the cells of the rest of the corallum have dried away, as increase went on above. Another example is shown on page 34, in which the living part had a length of one eighth of an inch. The Goniopora, on page 32, is still another example of the process; but here the living part combines a great number of polyps: these are growing and budding with all the exuberance of life, while below, the old polyps gradually disappear, and even their cells become superficial and fade out. Trees of Madrepores may also have their limits—all below a certain distance from the summit being dead; and this distance will differ for different species. But this is not a limit to the existence of the zoöthome, even though a slender tree or shrub, or of its flourishing state; for the dead coral below is firm rock itself, often stronger than ordinary limestone or marble, and serves as an ever-rising basement for the still expanding and rising zoöphyte.



CAULASTRÆA FURCATA, D.

But this death is not in progress alone at the base of the column or branch. Generally the *whole interior* of a corallum is dead, a result of the same process with that just explained. Thus, a Madrepora, although the branch may be an inch in diameter, is alive only to the depth of a line or two, the growing polyps of the surface having progressively died at the lower or inner extremity as they increased outward.

The large domes of Astræas, which have been stated to attain sometimes a diameter of ten or fifteen feet, and are alive over the whole surface, owing to a symmetrical and unlimited mode of budding, are nothing but lifeless coral throughout the interior. Could the living portion be separated, it would form a hemispherical shell of polyps, in most species about half an inch thick. In some Porites of the same size, the whole mass is lifeless, excepting the exterior for a sixth of an inch in depth.

With such a mode of increase, there is no necessary limit to the growth of zoöphytes. The rising column may increase upward indefinitely, until it reaches the surface of the sea, and then death will ensue simply from exposure, and not from any failure in its powers of life. The huge domes may enlarge till the exposure just mentioned causes the death of the summit, and leaves only the sides to grow, and these may still widen, it may be indefinitely. Moreover, it is evident that if the land supporting the coral domes and trees were gradually sinking, the upward increase might go on without limit.

In the following of death after life "æquo pede," there is obedience to the universal law. And yet the polyps, through this ever yielding a little by piecemeal, seem to get the better of the law, and in some instances secure for themselves almost perpetual youth, or at least a very great age. Of the polyps over an Astræa hemisphere, none ever die as long as the dome is in a condition of growth ; and the first budding individual, or at least its mouth and stomach, is among the tens of thousands that constitute the living exterior of the dome of fifteen feet diameter. In the Madrepore, the terminal parent-polyp of a branch grows on without being reached by the death-

warrant that takes off at last the commoners about the base of the tree; it keeps growing and budding, and the tree thus continues its increase.

The death of the polyps about the base of a coral tree would expose it, seemingly, to immediate wear from the waters around it, especially as the texture is usually porous. But nature is not without an expedient to prevent to some extent this catastrophe.

In the first place, there is often a *perithcca* over the dead corallum—that is, an outer impervious layer of carbonate of lime, secreted by the lower edge of the series of dying polyps, a fact in the *Goniopora columna* figured on page 32. Then, further, the dead surface becomes the resting-place of numberless small encrusting species of corals, besides Nullipores, Serpulas, and some Mollusks. In many instances, the lichen-like Nullipore grows at the same rate with the rate of death in the zoöphyte, and keeps itself up to the very limit of the living part. The dead trunk of the forest becomes covered with lichens and fungi, or, in tropical climes, with other foliage and flowers; so among the coral productions of the sea, there are forms of life which replace the dying polyp. The process of wear is frequently thus prevented.

The older polyps, before death, often increase their coral secretions also within, filling the pores as the tissues occupying them dwindle, and thus render the corallum nearly solid; and this is another means by which the trees of coral growth, though of slender form, are increased in strength and endurance.

The facility with which polyps repair a wound, aids in carrying forward the results above described. The breaking of a branch is no serious injury to a zoöphyte. There is often some degree of sensibility apparent throughout a clump even when of considerable size, and the shock, therefore, may occasion the polyps to close. But, in an hour, or perhaps much less time, their tentacles will again have expanded; and such as were torn by the fracture will be in the process of complete restoration to their former size and powers. The

fragment broken off, dropping in a favourable place, would become the germ of another coral plant, its base cementing by means of new coral secretions to the rock on which it might rest; or, if still in contact with any part of the parent tree, it would be reunited and continue to grow as before. The coral zoöphyte may be levelled by transported masses swept over it by the waves; yet, like the trodden sod, it sprouts again, and continues to grow and flourish as before. The sod, however, has roots which are still unhurt; while the zoöphyte, which may be dead at base, has a root—a source or centre of life—in every polyp that blossoms over its surface. Each animal might live and grow if separated from the rest, and would ultimately produce a mature zoöphyte.

V. COMPOSITION OF CORAL.

Ordinary corals have a hardness a little above that of common limestone or marble. The ringing sound given, when coral is struck with a hammer, indicates this superior hardness. It is possible that it may be owing to the carbonate of lime being in the state of aragonite, whose hardness exceeds a little that of ordinary carbonate of lime or calcite. It is a common error of old date to suppose that coral when first removed from the water is soft, and afterward hardens on exposure. For, in fact, there is scarcely an appreciable difference; the live coral may have a slimy feel in the fingers; but if washed clean of the animal matter, it is found to be quite firm. The water with which it is penetrated may contain a trace of lime in solution, which evaporates on drying, and adds slightly to the strength of the coral; but the change is hardly appreciable. A branched Madrepore rings on being struck when first collected; and a blow in any part puts in hazard every branch throughout it, on account of its elasticity and brittleness. The specific gravity of coral varies from 2·5 to 2·8: 2·523 was the average from fifteen specimens examined by Prof. Silliman.

Chemically, the common reef-corals, of which the branching Madrepora and the massive Astræas are good examples,

consist almost wholly of carbonate of lime, the same ingredient which constitutes ordinary limestone. In 100 parts, 95 to 98 parts are of this constituent; of the remainder, there are 1½ to 4 parts of organic matter, and some earthy ingredients amounting usually to less than 1 per cent. These earthy ingredients are phosphate of lime, with sometimes a trace of silica. A trace of fluorine also has been observed.

S. P. Sharples found the following constitution for the species below named (*Am. Jour. Sci.*, III., i. 168).

	CARBONATE OF LIME.	PHOSPHATE OF LIME.	WATER AND ORGANIC MATTERS.
Oculina arbuscula, N. Car.	95·37	0·84	3·79
Manicina areolata, Florida	96·54	0·50	2·96
Agaricia agaricites	97·73	0·53	1·64
Siderastræa radians	97·30	0·28	2·42
Madrepora cervicornis	98·07	0·32	1·93
Madrepora palmata	97·19	0·78	2·81

Forchhammer found 2·1 per cent. of magnesia in *Corallium rubrum*, and 6·36 in *Isis hippuris*.

The sea-water, and the ordinary food of the polyps, are evidently the sources from which the ingredients of coral are obtained. The same powers of elaboration which exist in other animals belong to polyps; for this function, as has been remarked, is the lowest attribute of vitality. Neither is it at all necessary to inquire whether the lime in sea-water exists as carbonate, or sulphate, or whether chloride of calcium takes the place of these. The powers of life may make from the elements present whatever results the functions of the animal require.

The proportion of lime salts which occurs in the water of the ocean is about $\frac{1}{24}$ to $\frac{1}{38}$ of all the ingredients in solution. The lime is mainly in the state of sulphate. Bischof states that the proportion of salts of all kinds in sea-water averages 3·527 per cent.; and in 100 parts of this, 75·79 are chloride of sodium, 9·16 chloride of magnesium, 3·66 chloride of potassium, 1·18 bromide of sodium, 4·62 sulphate of lime or

gypsum, and 5·597 sulphate of magnesia, = 100. This corresponds to about 16½ parts of sulphate of lime to 10,000 of water.

Fluorine has also been detected in sea-water; so that all the ingredients of coral are actually contained in the waters of the ocean.

It has been common to attribute the origin of the lime of corals to the existence of carbonic-acid springs in the vicinity of coral islands. But it is an objection to such a hypothesis, that, in the first place, the facts do not require it; and, in the second, there is no foundation for it. The islands have been supposed to rest on volcanic summits, thus making one hypothesis the basis of another. Carbonic-acid springs are by no means a universal attendant on volcanic action. The Pacific affords no one fact in support of such an opinion. There are none on Hawaii, where are the most active fires in Polynesia; and the many explorations of the Society and Navigator Islands have brought none to light. Some of the largest reefs of the Pacific, those of Australia and New Caledonia, occur where there is no evidence of former volcanic action.

The currents of the Pacific are constantly bringing new supplies of water over the growing coral beds, and the whole ocean is thus engaged in contributing to their nutriment. Fish, mollusks, and zoöphytes are thus provided with earthy ingredients for their calcareous secretions, if their food fails of giving the necessary amount; and, by means of the powers of animal life, bones, shells, and corals alike are formed.

The origin of the lime in solution throughout the ocean is an inquiry foreign to our present subject. It is sufficient here to show that this lime, whatever its source, is adequate to explain all the results under consideration.

II. HYDROIDS.

The annexed sketch represents a Hydra as it often occurs attached to the under surface of a floating leaf—that of a species of Lemna. The animal is seldom over half an inch

long. It has the form of a polyp, with long slender tentacles; and, besides these tentacles with their lasso-cells, it has no special organs except a mouth and a tubular stomach. Like the fabled Hydra, if its head be cut off another will grow out; and any fragment will, in the course of a short time, become a perfect Hydra, supplying head, or tail, or whatever is wanting: and hence the name given to the genus by Linnæus.

The Hydra is the type of a large group of species. It buds, but the buds drop off soon, and hence its compound groups are always small, and usually it is single. But other kinds multiply by buds that are persistent, and almost indefinitely so; and they thus make membranous coralla of considerable size and often of much beauty.



HYDRA.

The species figured on p. 78, the *Hydrallmania Falcata*, is one of them; in allusion to its delicate plumes, it is called Plumularia. Along the branches, there are minute cells, each of which was the seat of one of the little Hydra-like animals (in this not a fourth of a line long), and usually with short tentacles spread out star-like. Other kinds are simple branching threads, and sometimes the cells are goblet-shaped and terminal. The Tubulariæ grow in tufts of thread-like tubes, and have a star-shaped flower at top, often half an inch in diameter, with a proboscis-like mouth at the centre. In Coryne, a closely-related genus, the tentacles are shorter, and somewhat scattered about the club-shaped or probosciform head of the stem, so that the animal at top is far from star-shaped or graceful in form; it is in fact a very clumsy unshapen thing for a Radiate.

To the animal of the Coryne, that of the very common, and often large, corals, called Millepores, is closely related, as first

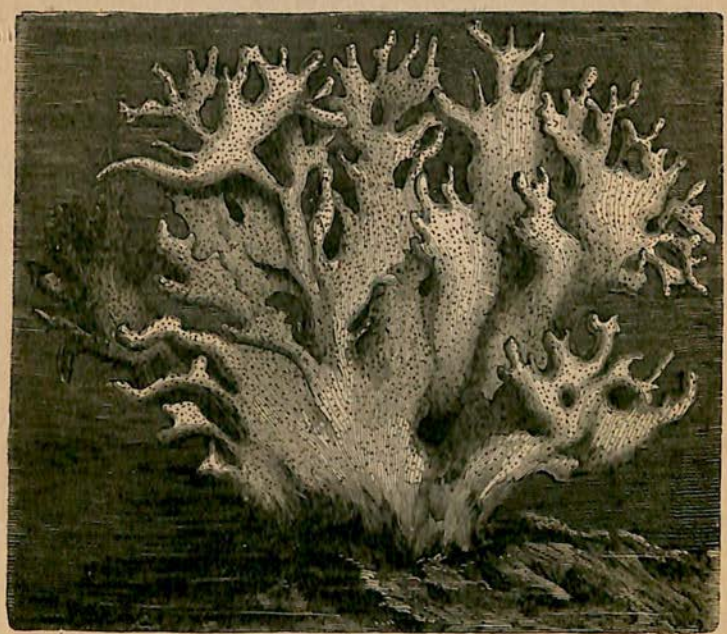
detected by Agassiz on one of his cruises to the reefs of Florida.



HYDRALLMANIA FALCATA.

The author often had Millepore corals under study in the

Pacific, and waited long for the expansion of the animals, but was never gratified by their making their appearance. Agassiz observes that they are very slow in expanding themselves. When expanded, they have no resemblance to true polyps. There is simply a fleshy tube with a mouth at top and a few small rounded prominences in place of tentacles, four of



MILLEPORA ALCICORNIS.

them sometimes largest. The next figure, from Agassiz, shows, much enlarged, a portion of a branch of the *Millepora alcicornis* with the animals expanded, and the small figure *a*, near the top of the cut, gives the natural size of the same.

The corals of the Milleporæ are solid and stony, as much so as any in coral seas. They have generally a smooth

surface, and are always without any prominent calicles, there being only very minute rounded punctures over the surface, from which the animals show themselves. The cells in the corallum are divided parallel to the surface by very thin plates or tables, as in the Pocilliporæ and Favosites; and they were formerly classed, therefore, with other tabulate corals.

S. P. Sharples found the coral of *M. alcicornis* to consist of 97·46 per cent. of carbonate of lime, 0·27 of phosphate of lime, and 2·54 of water and organic matters. The Millepores are very abundant corals, and eminently so in the West India seas, contributing largely to the material of the reefs.

The Hydroids were long considered polyps. But they have been found to give origin to Medusæ, or jelly-fishes, and it is now proved that they are only an intermediate stage in the development of Medusæ, between the embryo state and that of the adult or Medusa state. The Millepores afford, therefore, examples of coral-making by species of the class of Acalephs. Many of these Medusæ and their Hydroids will be found illustrated in the admirable work of Alexander and Mrs. L. Agassiz, entitled "Sea-Side Studies,"—an excellent companion for all who take pleasure in sea-shore rambles.



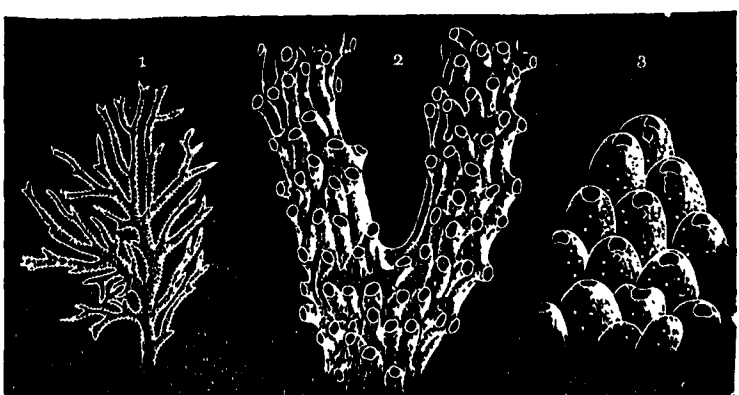
ANIMALS OF MILLEPORA ALCICORNIS, MUCH ENLARGED.

Another genus of corals referred to the Millepora group occurs in the East Indies, the species of which is remarkable for having within an indigo-blue colour; it is called *Heliopora cærulea*, the generic name, from the Greek for *sun*, alluding to the minute *round* polyp-cells. This and the true Milleporæ are coral-reef species. A few allied species occur in colder waters, and for these the genus Pliobothrus has been instituted; one species has been described by De Pourtales, from the deep waters off the Florida reef. The ancient

corals of the Chætetes family were possibly, like the Millepores, Acaleph corals, as suggested by Agassiz. Others have suggested, with perhaps better reason, that they were Bryozoan.

III. BRYOZOANS.

The Bryozoans are very small animals, and look much like Hydroids. Although belonging to the sub-kingdom of Mollusks, they are externally polyp-like, having a circle or ellipse of slender tentacles around the mouth. But, in internal structure, and all of the animal below the head, they are Mollusks. They form delicate corals, membranous or calcareous, made up of minute, cabin-like cells, which are either very thin crusts on sea-weeds, rocks, or other supports, or



1, 2, HORNERA LICHENOIDES; 3, DISCOPORA SKENEI SMITT.

slender moss-like tufts, or graceful groups of thin, curving plates, or net-like fronds; and sometimes thread-like lines, or open reticulations.

Occasionally they make large, massive corals, from the growing of plate over plate. One of these massive species, *Escharella variabilis*, is common on the coast of the United States from Cape Cod southward.

The first of the foregoing figures, from Smitt's work on the Bryozoans, represents one of the delicately branching species, of natural size; and the second, a portion of the same, much enlarged. The latter figure shows that the branches are made up of minute cells. From each cell, when alive, the bryozoum extends a circlet of tentacles, less than a line in diameter.

The incrusting kinds are common in all seas. The crust of cells they make is often thinner than paper. A portion of such a crust is represented, enlarged, in figure 3. When expanded, the surface is covered over with the delicate flower-like bryozoa. A low magnifying power is necessary to observe them distinctly. The animals, unlike true polyps and the Hydroids, have two extremities to the alimentary canal, and in this, and other points, they are Molluscan in type.

The cells of a group never have connection with a common tube, as in the Hydroids; on the contrary, each little Bryozoum, in the compound group or zoöthome, is wholly independent of the rest in its alimentary canal.

Bryozoans occur in all seas and at all depths; and in early Paleozoic time they contributed largely to the making of limestone strata. The two specimens figured on the preceding page occur on the coast of New England, as well as in the seas of North Europe.

IV. NULLIPORES.

The more important species of the Vegetable Kingdom that afford stony material for coral reefs are called Nullipores. They are true Algæ or sea-weeds, although so completely stony and solid that nothing in their aspect is plant-like. They form thick, or thin, stony incrustations over surfaces of dead corals, or coral rock, occasionally knobby or branching, and often

spreading lichen-like. Species of these forms belong to the genus Melobesia.

They have the aspect of ordinary coral, especially the Millepores, but may be distinguished from these species by their having no cells, not even any of the pin-punctures of those species.

Besides the more stony kinds, there are delicate species, often jointed, called *Corallines*, which secrete only a little lime in their tissues, and have a more plant-like look. Even these grow so abundantly on some coasts, that, when broken up and accumulated along the shore by the sea, they may make thick calcareous deposits. Agassiz has described such beds as having considerable extent in the Florida seas.

V. THE REEF-FORMING CORALS AND THE CAUSES INFLUENCING THEIR GROWTH AND DISTRIBUTION.

I. Distribution in Latitude.

Reef-forming species are the warm-water corals of the globe. A general survey of the facts connected with the temperature of the ocean in coral-reef seas appears to sustain the conclusion that they are confined to waters which, through even the coldest winter month, have a mean temperature not below 68° F. Under the equator, the surface waters in the hotter part of the ocean have the temperature of 85° F. in the Pacific, and 83° F. in the Atlantic. The range from 68° F. to 85° F. is, therefore, not too great for reef-making species.

An isothermal line, crossing the ocean where this winter temperature of the sea is experienced, one north of the equator, and another south, bending in its course toward or from the equator, wherever the marine currents change its position, will include all the growing reefs of the world; and the area of waters may be properly called the *coral-reef seas*.

This isothermal boundary line, the *isocryme* (or cold-water line) of 68° F., extends, through mid-ocean, near the parallel

of 28°; but in the vicinity of the continents it varies greatly from this, as explained beyond in the course of remarks on the geographical distribution of reefs. It is to be observed that the temperature of 68° F. is a temporary extreme—not that under which the polyps will flourish. Except for a short period, the waters near the limits of the coral seas are much warmer; the mean for the year is about 73½° F. in the North Pacific, and 70° F. in the South; from which it may be inferred that the summer mean would be as high at least as 78° and 74° F.

Over the sea thus limited coral reefs grow luxuriantly, yet in greatest profusion and widest variety through its hotter portions. Drawing the isocryme of 74° F. (that is, the isotherm for 74° F. as the mean for the coldest month) around the globe, the coral-reef seas are divided, both north and south of the equator, into two regions, a *torrid*, and a *subtorrid*, as they are named by the author (see Chart beyond, from the Author's Report on Crustacea); and these correspond, as seen below, to a marked difference in the corals which they grow.

Further, the torrid region should be divided, as the distribution of corals show, into a *warmer* and a *cooler* torrid, the isocryme separating the two being probably that of 78°.

But, before considering the facts connected with the geographical distribution of existing coral-reef species, it is important to have a correct apprehension of what are these reef species as distinct from those of colder and deeper seas.

The coral-reef species of corals are the following:—

1. In the Astræa tribe (Astræacea), all the many known species.

2. In the Fungia tribe (Fungacea), almost all known species, the only exceptions at present known being two free species found much below coral-reef depths, in the Florida seas, by C. F. de Pourtales, one of them, at a depth of 450 fathoms.

3. In the Oculina tribe (Oculinacea), all of the Orbicellids; part of the Oculinids and Stylasterids; some of the Caryophyllids, Astrangids and Stylophorids; all of the Pocilloporids.

4. In the Madrepora tribe (Madreporacea), all of the Madreporids and Poritids; many of the Dendrophyllia family or Eupsammids.

5. Among Alcyonoids, numerous species of the Alcyonium and Gorgonia tribes, and some of the Pennatulacea.

6. Among Hydroids, the Millepores and Heliopores.

7. Among Algæ, many Nullipores and Corallines.

The corals of *colder* waters, either outside of the coral-reef seas, or at considerable depths within them, comprise, accordingly, the following:—

1. A very few Fungids.

2. Some of the Oculinids; many of the Astrangids and Caryophyllids; many Stylasterids; a few Stylophorids.

3. Many of the Eupsammids.

4. Some of the Gorgonia and Pennatula tribes, and a few of the Alcyonium tribe.

5. A few Milleporids of the genus Pliobothrus.

A large proportion of the cold-water species are solitary polyps.

Through the *torrid* region, in the central and western Pacific, that is, within 15° to 18° of the equator, where the temperature of the surface is never below 74° F. for any month of the year, all the prominent genera of reef-forming species are abundantly represented—those of the Astræacea, Fungacea, Oculinacea, Madreporacea, Alcyonoids, Millepores and Nullipores. The Feejee seas afford magnificent examples of these torrid region productions. Astræas and Mæandrinas grow there in their fullest perfection; Madrepores add flowering shrubbery of many kinds, besides large vases and spreading folia; some of these folia over six feet in expanse. Mussæ and related species produce clumps of larger flowers; Merulinæ, Echinoporæ, Gemmiporæ and Montiporæ form groups of gracefully infolded or spreading leaves; Pavoniæ, Pocilliporæ, Seriatoporæ and Porites, branching tufts of a great variety of forms; Tubipores and Xeniæ, beds or masses of the most delicately-tinted pinks; Sponggodiæ, large pendant clusters of orange and crimson; and Fungiæ display their

broad disks in the spaces among the other kinds. Many of the species may be gathered from the shallow pools about the reefs. But with a native canoe, and a Feejee to paddle and dive, the scenes in the deeper waters may not only be enjoyed, but boat-loads of the beautiful corals be easily secured.

The Hawaian Islands, in the North Pacific, between the latitudes 19° and 22°, are outside of the torrid zone of oceanic temperature, in the *subtorrid*, and the corals are consequently less luxuriant and much fewer in species. There are no Madrepores, and but few of the Astræa and Fungia tribes; while there is a profusion of corals of the hardier genera, Porites and Pocilliporæ.

The genera of corals occurring in the East Indies and Red Sea are mainly the same as in the Central Pacific; and the same also occur on the coast of Zanzibar.

To the eastward of the Pacific coral islands, the Paumotus, which are within the limits of the torrid region, the variety of species and genera is large, but less so than to the westward. Special facts respecting this sea have not been obtained. The author's observations were confined to the groups of islands farther west, the department of corals having been in the hands of another during the earlier part of the cruise of the Government Expedition with which he was connected.

The Gulf of Panama and the neighbouring seas, north to the extremity of the California peninsula and south to Guayaquil, lie within the *torrid* region; but in the cooler part of it. The species have throughout a Pacific character, and nothing of the West Indian; but they are few in number, and are much restricted in genera. There are none, yet known, of the Astræacea, and no Madrepores. Prof. Verrill, through the study of collections made by F. H. Bradley and others, has observed that there are, near Panama, a few species of Porites and Dendrophylliæ, a Stephanaria (near Pavonia), two species of Pocilliporæ, two of Pavoniæ, one of them very large and named *P. gigantea* V., several Astrangids, and a few other small species, besides a large variety under the Gorgonia tribe. At La Paz, on the California peninsula at the entrance

to the Gulf, occur a small but beautiful Fungia (*F. elegans* V.), three Porites, a Dendrophyllia, a Pocillipora, some Astrangids, and many fine Gorgoniæ. The character of the species is that of the *cooler torrid* region, rather than that of the warmer torrid.

Owing to the cold oceanic currents of the eastern border of the Pacific—one of which, that up the South American coast, is so strong and chilling as to push the southern isocryme of 68°, the coral-sea boundary, even beyond the Galapagos, and north of the equator—the coral-reef sea, just east of Panama, is narrowed to 20°, which is 36° less of width than it has in mid-ocean; and this suggests that these currents, by their temperature, as well as by *their usual westward direction*, have proved an obstacle to the transfer of mid-ocean species to the Panama coast.

In the West Indies the reefs lie within the limits of the isocryme of 74° F., or the torrid region; and yet the variety of species and genera is very small compared with the same in the Central Pacific. The region contains some large Madrepores, the *M. palmata*, a spreading foliaceous species that forms clumps two yards in diameter; *M. cervicornis*, a stout, sparsely-branched tree-like species, which attains a height of fifteen feet; *M. prolifera*, a handsome shrub-like species, of rather crowded branches; besides others; and these are marks of the existence of the *warmer torrid* region; yet the sea has not as high a temperature as the hottest part of the Pacific. The species of the Astræa tribe are few in number, and among the largest kinds are the Mæandrinæ (the Diploria being here included). None of the free Fungidæ are known excepting the two species in deep water, and none of the Pavoniæ among the compound species; but the massive Siderinæ (Siderastrææ) are common, and the foliaceous Agariciæ and Mycedia. Of the Oculina tribe, species of Oculina, Cladocora and Astrangia are relatively more numerous than in the Central Pacific; but there are none of the Pocilliporids, which are common both in the torrid and subtorrid regions of the Pacific. Millepores are very common. Gorgoniæ, are of many species.

Professor Verrill observes that not a single West Indian coral occurs on the Panama coast, although, on the opposite coast, at Aspinwall, there are found nearly all the reef-building species of Florida, viz.: *Porites astræoides* Lmk., *P. clavaria* Lmk., *Madrepora palmata* L., *M. cervicornis* L., *M. prolifera* L., *Mæandrida clivosa* V., *M. labyrinthica*, *M. sinuosa* Les., with other species of Mæandrina, *Manicina areolata* Ehr., *Siderastræa* (*Siderina*) *radiata* V., *S. galaxea* Bl., *Agaricia agaricites*, *Orbicella cavernosa* V., *O. annularis* D. Moreover no West Indian species is known to be identical with any from the Pacific or Indian Ocean.

The reefs of the Brazilian coast south of Cape Roque lie in the subtorrid region of oceanic temperature, or between the isocrymes of 74° and 68°. The reef corals extend as far south as Cape Frio, according to Professor C. F. Hartt. The species, as determined by Professor Verrill, from Professor Hartt's collections, resemble the West Indian. All species of Madrepora, Mæandrina, Diploria, Manicina, Oculina, genera eminently characteristic of the West Indies, appear to be wanting, while the most important reef-making genera are *Favia*, *Acanthastræa*, *Orbicella*, *Siderastræa*, *Porites*, and *Millepora*, and also, of less importance, *Mussa* and some others. A few species, viz.: *Siderastræa stellata* V., *Orbicella aperta* V., *Astræa gravida* V., and *Porites solida* V., are very close to West Indian species; and *Millepora alcicornis* is an identical species, though different in variety.

The Bermudas are in the North Atlantic subtorrid region, in the range of the Gulf Stream. The few reef-making species that occur there are all West Indian, viz: The species of the Astræa tribe, *Isophyllia dipsacea*, *I. rigida*, *Diploria cerebriformis;* of the Oculina tribe, *Oculina diffusa*, *Oculina varicosa*, *Oculina pallens*, *Oculina Valenciennesii;* of the Fungia tribe, *Siderastræa radians*, *Mycedium fragile;* of the Madrepora tribe, *Porites clavaria;* also the *Millepora alcicornis*, and the common West India Alcyonoids, *Gorgonia flabellum*, *Plexaura crassa* Lx., *Pl. flexuosa* Lx., *Pl. homomalla* Lx., *Pterogorgia Americana* Ehr., *Pt. acerosa*, Ehr.

The facts presented are sufficient to show that temperature has much to do with the distribution of reef-corals in latitude, while proving also that regional peculiarities exist that are not thus accounted for.

II. Distribution in Depth.

Quoy and Gaymard were the first authors who ascertained that reef-forming corals were confined to small depths, contrary to the account of Foster and the early navigators. The mistake of previous voyagers was a natural one, for coral reefs were proved to stand in an unfathomable ocean; yet it was from the first a mere opinion, as the fact of corals growing at such depths had never been ascertained. The few species which are met with in deep waters appear to be sparsely scattered, and nowhere form accumulations or beds.

The above-mentioned authors, who explored the Pacific in the *Uranie* under D'Urville (and afterward also in the *Astrolabe*), concluded from their observations that five or six fathoms (30 or 36 feet) limited their downward distribution. Ehrenberg, by his observations on the reefs of the Red Sea, confirmed the observations of Quoy and Gaymard; he concluded that living corals do not occur beyond six fathoms. Mr. Stutchbury, after a visit to some of the Paumotus and Tahiti, remarks, in Volume I. of the West of England Journal, that the living clumps do not rise from a greater depth than sixteen or seventeen fathoms.

Mr. Darwin, who traversed the Pacific with Captain Fitzroy, R.N., gives twenty fathoms as not too great a range.

In his soundings off the fringing reefs of Mauritius, in the Indian Ocean, on the leeward side of the island, he observed especially two large species of Madrepores, and two of Astræa; and a *Millepora* down to fifteen fathoms, with also, in the deeper parts, Seriatopora; between fifteen and twenty fathoms a bottom mostly of sand, but partly covered with the Seriatopora, with a fragment of one of the Madrepores at twenty fathoms. He states that Capt. Moresby, in

his survey of the Maldives and Chagos group, found, at seven or eight fathoms, great masses of living coral; at ten fathoms, the same in groups with patches of white sand between; and, at a little greater depth, a smooth steep slope without any living coral; and further, on the Padua Bank, the northern part of the Laccadive group, which had a depth of twenty-five to thirty-five fathoms, he saw only dead coral, while on other banks in the same group, ten or twelve fathoms under water, there was growing coral.

In the Red Sea, however, according to Captain Moresby and Lieutenant Wellstead, there are, to the north, large beds of living corals at a depth of twenty-five fathoms, and the anchors were often entangled by them; and he attributes this depth, so much greater than reported by Ehrenberg, to the peculiar purity, or freedom from sediment, of the waters at that place. Kotzebue states that in some lagoons of the Marshall group he observed living corals at a depth of twenty-five fathoms, or one hundred and fifty feet.

Professor Agassiz observes that about the Florida reefs the reef-building corals do not extend below ten fathoms. Mr. L. F. de Pourtales states that he found species of Oculina and Cladocora off the Florida reefs living to a depth of fifteen fathoms.

It thus appears that all recent investigators since Quoy and Gaymard have agreed in assigning a comparatively small depth to growing corals. The observations on this point, made during the cruise of the Wilkes Exploring Expedition, tend to confirm this opinion.

The conclusion is borne out by the fact that soundings in the course of the various and extensive surveys afford no evidence of growing coral beyond twenty fathoms. Where the depth was fifteen fathoms, coral sand and fragments were almost uniformly reported. Among the Feejee Islands, the extent of coral-reef grounds surveyed was many hundreds of square miles, besides the harbours more carefully examined. The reefs of the Navigator Islands were also sounded out, with others at the Society group, besides numerous coral

islands; and through all these regions no evidence was obtained of corals living at a greater depth than fifteen or twenty fathoms. Within the reefs west of Viti Lebu and Vanua Lebu, the anchor of the *Peacock* was dropped sixty times in water from twelve to twenty-four fathoms deep, and in no case struck among growing corals; it usually sunk into a muddy or sandy bottom. Patches of reef were encountered at times, but they were at a less depth than twelve fathoms. By means of a drag, occasionally dropped in the same channels, some fleshy Alcyonia and a few Hydroids were brought up, but no reef-forming species.

Outside of the reef of Upolu, corals were seen by the writer growing in twelve fathoms. Lieutenant Emmons brought up with a boat-anchor a large Dendrophyllia from a depth of fourteen and a half fathoms at the Feejees; and this species was afterwards found near the surface. But Dendrophyllia, it may be remembered, is one of the deep-water genera.

These facts, it may be said, are only negative, as the sounding-lead, especially in the manner it is thrown in surveys, would fail of giving decisive results. The character of a growing coral bed is so strongly marked in its uneven surface, its deep holes and many entangling stems, to the vexation of the surveyor, that in general the danger of mistake is small. But allowing uncertainty as great as supposed, there can be little doubt after so numerous observations over so extended regions of reefs.

The depth of the water in harbours and about shores where there is no coral, confirms the view here presented. At Upolu, the depth of the harbours varies generally from twelve to twenty fathoms. On the south side of this island, off Falealili, one hundred yards from the rocky shores, Lieutenant Perry found bare rocks in eighteen and nineteen fathoms, with no evidence of coral. There is no cause here which will explain the absence of coral, except the depth of water; for corals and coral reefs abound on most other parts of Upolu. Below Falelatai, of the same island, an equal depth was found, with no coral. Off the east cape of Falifa harbour, on the north

side of Upolu, Lieutenant Emmons found no coral, although the depth was but eighteen fathoms. About the outer capes of Fungasa harbour, Tutuila, there was no coral, with a depth of fifteen to twenty fathoms; and a line of soundings across from cape to cape afforded a bottom of sand and shells, in fifteen to twenty-one and a half fathoms. About the capes of Oafonu harbour, on the same island, there was no coral, with a depth of fifteen fathoms.

Similar results were obtained about all the islands surveyed, as the charts satisfactorily show. There is hence little room to doubt that *twenty fathoms* may be received as the ordinary limit in depth of reef corals in the tropics.

It may however be much less, possibly not over half this, on the colder border of the coral-reef seas, as, for example, at the Hawaian Islands and the atolls northwest of that group. It is natural that regions so little favourable for corals on account of the temperature should differ in this respect from those in the warmer tropics.

It may be here remarked, that soundings with reference to this subject are liable to be incorrectly reported, by persons who have not particularly studied living zoöphytes. It is of the utmost importance, in order that an observation supposed to prove the occurrence of living coral should be of any value, that fragments should be brought up for examination, in order that it may be unequivocally determined whether the corals are living or not. Dead corals may make impressions on a lead as perfectly as living ones.

As to the origin of this small range in depth—about 120 feet—temperature must be admitted as one cause, it having been proved to be predominant with regard to distribution of life throughout the extent and depths of the ocean. Yet it can hardly in this case be the only cause. The range of temperature 85° to 74° gives sufficient heat for the development of the greater part of coral-reef species; and yet the temperature at the 100 foot plane in the middle Pacific is mostly above 74.°

III. Local Causes influencing Distribution.

Coral-making species generally require pure ocean water, and they especially abound in the broad inner channels among the reefs, within the large lagoons, and in the shallow waters outside of the breakers. It is therefore an assertion wide from the fact that only small corals grow in the lagoons and channels, though true of lagoons and channels of small size, or of such parts of the larger channels as immediately adjoin the mouths of fresh-water streams.

There are undoubtedly species especially fitted for the open ocean; but as peculiar conveniences are required for the collection of zoöphytes outside of the line of breakers, we have not the facts necessary for an exact list of such species. From the very abundant masses of Astræas, Mæandrinas, Porites, and Madrepores thrown up by the waves on the exposed reefs, it was evident that these genera were well represented in the outer seas. In the Paumotus, the single individuals of Porites lying upon the shores were at times six or eight feet in diameter. Around the Duke of York's Island, the bottom was observed to be covered with small branching and foliaceous Montipores, as delicate as any of the species in more protected waters.

Species of the same genera grow in the face of the breakers, and some are identical with those that occur also in deeper waters. Numerous Astræas, Mæandrinas, and Madrepores grow at the outer edge of the reefs where the waves come tumbling in with their full force. There are also many Millepores and some Porites and Pocillipores in the same places. But the weaker Montipores, excepting incrusting species, are found in stiller waters either deep or shallow.

Again, the same genera occur in the shallow waters of the reef inside of the breakers. Astræas, Mæandrinas and Pocillipores are not uncommon, though requiring pure waters. There are also Madrepores, some growing even in impure waters. One species was the only coral observed in the lagoon of

Honden Island (Paumotus), all others having disappeared, owing to its imperfect connection with the sea. Upon the reefs inclosing the harbour of Rewa (Viti Lebu), where a large river, three hundred yards wide, empties, which during freshets enables vessels at anchor two and a half miles off its mouth to dip up fresh water alongside, there is a single porous species of Madrepora (*M. cribripora*), growing here and there in patches over a surface of dead coral rock or sand. In similar places about other regions, species of Porites are most common. In many instances, the living Porites were seen standing six inches above low tide, where they were exposed to sunshine and to rains; and associated with them in such exposed situations there were usually great numbers of Alcyonia and Xeniæ. The Siderinæ endure well exposure to the air.

The exposure of six inches above low tide, where the tide is six feet, as in the Feejees, is of much shorter duration than in the Paumotus, where the tide is less than half this amount; and consequently the height of growing coral, as compared with low-tide level, varies with the height of the tides.

Porites also occur in the impure waters adjoining the shores; and the massive species in such places commonly spread out into flat disks, the top having died from the deposition of sediment upon it.

The effects of sediment on growing zoöphytes are strongly marked, and may be often perceived when a mingling of fresh water alone produces little influence. We have mentioned that the Porites are reduced to flattened masses by the lodgment of sediment. The same takes place with the hemispheres of Astræa; and it is not uncommon that in this way large areas at top are deprived of life. The other portions still live unaffected by the injury thus sustained. Even the Fungiæ, which are broad simple species, are occasionally destroyed over a part of the disk through the same cause, and yet the rest remains alive. It is natural, therefore, that wherever streams or currents are moving or transporting sediment, there no corals

grow; and for the same reason we find few living zoöphytes upon sandy or muddy shores.

The small lagoons, when shut out from the influx of the sea, are often rendered too salt for growing zoöphytes, in consequence of evaporation,—a condition of the lagoon of Enderby's Island.

They also are liable to become highly heated by the sun, which likewise would lead to their depopulation.

Coral zoöphytes sometimes suffer injury from being near large fleshy Alcyonia, whose crowded drooping branches lying over against them, destroy the polyps and mar the growing mass. Again, the dead parts of a zoöphyte, though in very many cases protected by incrusting nullipores, shells, bryozoans, &c., as already explained, in others is weakened by boring shells and sponges. Agassiz states in his paper on the Florida Reefs (Coast Survey Report for 1851): "Innumerable boring animals establish themselves in the lifeless stem, piercing holes in all directions into its interior, like so many augurs, dissolving its solid connection with the ground, and even penetrating far into the living portion of these compact communities. The number of these boring animals is quite incredible, and they belong to different families of the animal kingdom; among the most active and powerful we would mention the date-fish or Lithodomus, several Saxicavæ, Petricolæ, Acæ, and many worms, of which the Serpula is the largest and most destructive, inasmuch as it extends constantly through the living part of the coral stems, especially in the Mæandrina. On the loose basis of a Mæandrina, measuring less than two feet in diameter, we have counted not less than fifty holes of the date-fish—some large enough to admit a finger—besides hundreds of small ones made by worms. But however efficient these boring animals may be in preparing the coral stems for decay, there is yet another agent, perhaps still more destructive. We allude to the minute boring-sponges, which penetrate them in all directions, until they appear at last completely rotten through."

On the other hand, Serpulas and certain kinds of barnacles

(of the genus Creusia, &c.) penetrate living corals without injury to them. They attach themselves when young to the surface of the coral, and finally become imbedded by the increase of the zoöphyte, without producing any defacement of the surface, or affecting its growth. Many of these Serpulas grow with the same rapidity as the zoöphyte, and finally produce a long tube, which penetrates deep within the coral mass; and, when alive, they expand a large and brilliant circle or spiral of delicate rays, making a gorgeous display among the coral polyps. Instinct seems to guide these animals in selecting those corals which correspond with themselves in rate of growth; and there is in general a resemblance between the markings of a Creusia and the character of the radiations of the Astræa it inhabits.

In recapitulation, the three most influential causes of the exclusion of reef-forming corals from coasts are the following:

I. The too low temperature of the waters along shores.

II. The too great depth of the waters.

III. The proximity of the mouths of rivers, on account of which sediment is distributed along the coast adjoining and over the sea bottom.

IV. Rate of Growth of Corals.

The rate of growth of coral is a subject but little understood. We do not refer here to the progress of a reef in formation, which is another question complicated by many co-operating causes; but simply to the rapidity with which particular living species increase in size. There is no doubt that the rate is different for different species. It is moreover probable that it corresponds with the rate of growth of other allied polyps that do not secrete lime. The rate of growth of Actiniæ might give us an approximation to the rate of growth in coral animals of like size and general character; for the additional function of secreting lime would not necessarily retard the maturing of the polyp; and from the rate of growth of the same animals in the young state, we might

perhaps draw some inferences as to the rate in polyps of corresponding size. But no satisfactory observations on this point have yet been made.

Although the rapidity is undoubtedly far less than was formerly reported, the following facts from different sources seem to show that the rate is greater than has been of late believed. Mr. Darwin, citing from a manuscript by Dr. Allan, of Forres, some experiments made on the east coast of Madagascar, states that, in December, 1830, twenty corals were weighed, and then placed by him apart on a sandbank, in three feet water (low tide), and in the July following, each had nearly reached the surface and was quite immovable; and some had grown over the others. Mr. Darwin mentions also a statement made to him by Lieutenant Wellstead, that "in the Persian Gulf a ship had her copper bottom incrusted in the course of twenty months, with a layer of coral two feet thick,"—evidently to be accepted hesitatingly. He also speaks of a channel in the lagoon of Keeling atoll having been stopped up in less than ten years; and of the natives of the Maldives finding it necessary occasionally to root out, as they express it, coral knolls from their harbours.

Mr. Stutchbury describes a specimen consisting of a species of oyster whose age could not be over two years, incrusted by an Agaricia weighing two pounds nine ounces; but he does not state whether the shell was that of a living oyster or not.

Dr. D. F. Weinland states that on Hayti, in a small coral basin between the town of Corail and the island Caymites, never disturbed by vessels on account of the small depth of water, he observed several branches of the *Madrepora cervicornis* projecting above the surface of the water from three to five inches, all of which, down to the water level, were dead, as a result evidently of exposure to the air. This was in the month of June. He adds that all along the north shore of Hayti, the water level is from four to six feet higher in the winter season than during summer; and suggests that the

growth of three to five inches, above referred to, might have been made during the three winter months.

Duchassaing (in *L'Institut*, 1846, p. 117) observes that in two months some large individuals of *Madrepora prolifera*, which he broke away, were restored to their original size. More definite and valuable is the observation of M. L. F. de Pourtales, that a specimen of *Mæandrina labyrinthica*, measuring a foot in diameter, and four inches thick in the most convex part, was taken from a block of concrete at Fort Jefferson, Tortugas, which had been in the water only twenty years. Again, Major E. B. Hunt mentions, in the *American Journal of Science* for 1863, the fact of the growth of a Mæandrina at Key West, Florida, to a radius of six inches in twelve years, showing an average upward increase in this hemispherical coral of half an inch a year, if, as is evidently implied, this radius was a vertical radius. Major Hunt deposited specimens of corals of his collection near Fort Taylor, Key West, in the Yale College Museum, and three of these are labelled by him as having grown to their present size between the years 1846 and 1860, or in fourteen years. Two are specimens of *Oculina diffusa;* one is a clump four inches high and eight broad; and the other has about the same height. The weight of the first of these clumps is forty-four ounces. The rate of four inches in fourteen years would be equal to about $3\frac{1}{2}$ twelfths of an inch a year in height, or three and one-seventh ounces a year of solid coral. The other specimen is of the *Mæandrina clivosa* V.; it has a height of two-and-a-quarter inches, and a breadth of seven-and-a-half inches. This is equivalent to about a sixth of an inch of upward growth in fourteen years. The specimen weighs about eighteen ounces. It is not certain that with either of these specimens the germs commenced to grow the first year of this interval, and hence there is much doubt with regard to these calculations.

The following observations are from a paper read by Prof. Verrill before the Boston Society of Natural History in 1862. The wreck of a vessel, supposed to have been the British

frigate *Severn*, lost in 1793 near "Silver Bay," off Turk's Islands, is covered with growing corals. It lies (according to the journal of Mr. J. A. Whipple, by whom specimens were collected in 1857) in about four fathoms of water. One of the specimens was a mass of the species *Orbicella annularis*, shaped somewhat like a hat; it is attached to the top of a bell and spread outward on all sides. The thickness of the coral at the centre is about eight inches, and the breadth fifteen. Another specimen consisted of an olive jar and glass decanters cemented together by a mass, of like size, of the same species of coral. The interval since the wrecking of the vessel, to 1857, was sixty-four years, and if the corals commenced their growth immediately after the wreck, the increase of this species of coral is very slow.

The journal of Mr. Whipple, in the library of the same society, contains the records of his observations on the spot, and the efforts made to remove the corals in order to examine the wreck. The following are a few extracts made from it by Prof. Verrill :—

"*April* 21, 1857.—Moored our boat over the remains of a large wreck, . . its depth being from three to ten fathoms. I made the first descent in the armour. I found the bottom very uneven and covered with the remains of a man-of-war, what appeared to be the bow lying in a gulch, with the shanks of three large anchors, the palm of only one of which projected out of the coral rock.

"*April* 22.—Made a second descent and commenced examining in six fathoms of water on what appeared to be midships. All astern of this is thick branching coral (Madrepora), and it must have made very fast, the branches being twelve inches in diameter and sixteen feet in height. To look among it from the bottom reminds one of a thick forest of a heavy growth of timber. . . . This branched coral appears to grow where there is but very little iron, as I could see no guns or shot around its roots. Commenced examining the cannon with hammer and chisel. . . . Near these cannon, which must have been near the forward part of the ship, I commenced to work on a clear

space between the cannon. After breaking three inches of coral crust I found the collar-bone of a man, a brass regulating screw belonging to a quadrant, and some large lead bullets. . . . The magazine must be under the branch-coral, which has been sixty-four years growing. . . ."

Here we have a height of *sixteen feet* in a Madrepora attained in *sixty-four years*, or at the rate of three inches a year. Madrepores evidently grow with much greater rapidity than the massive corals.

Observations on the rate of growth of different species might easily be made by those residing in coral seas, either in the manner adopted by Mr. Allan (placing the specimens on a platform which could be raised for examination from time to time—say every five years), or by placing marks upon particular species where they are immovably fixed to the bottom. By inserting slender glass pins a certain distance from the summit of a Madrepore, its growth might be accurately measured from month to month. Two such pins in the surface of an Astræa would in the same manner, by the enlarging distance between, show the rate of increase in the circumference of the hemisphere; or if four were placed so as to inclose an area, and the number of polyps counted, the numerical increase of polyps resulting from budding might be ascertained. If specimens are selected, as done by Mr. Allan, it is important that they should be placed where other corals are growing in luxuriance, so as to be sure that there are no deleterious influences to retard growth. It is to be hoped that some of the foreign residents at the Sandwich, Society, Samoan, or Feejee Islands will take this subject in hand. There are also many parts of the West Indies where these investigations might be conveniently made.

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CHAPTER II.

STRUCTURE OF CORAL REEFS AND ISLANDS.

CORAL reefs and coral islands are structures of the same kind under somewhat different conditions. They are made in the same seas, by the same means; in fact, a coral island has in all cases been a coral reef through a large part of its history, and is so still over much of its area. The terms, however, are not synonymous. *Coral islands* are reefs that stand isolated in the ocean, away from other lands, whether now raised only to the water's edge and half submerged, or covered with vegetation; while the term *coral reef*, although used for reefs of coral in general, is more especially applied to those which occur along the shores of high islands and continents. There are peculiarities in each making it convenient to describe them separately.

I. CORAL REEFS.

GENERAL FEATURES.

Coral reefs are banks of coral rock built upon the sea-bottom about the shores of tropical lands. In the Pacific, these lands, with the exception of New Caledonia and others of large size to the westward, are islands of volcanic or igneous rocks, and they often rise to mountain heights. The coral reefs which skirt their shores are ordinarily wholly submerged at high

tide; but, at the ebb, they commonly present to view a broad, flat, bare surface of rock, just above the water level, strongly contrasting with the steep slopes of the incircled island.

Nearing in a vessel a coral-bound coast, the first sign of the reef, when the tide is welling in, is a line of heavy breakers, perhaps miles in length, off a great distance from the land. On closer view, some spots of bare reef may be distinguished as the waves retreat for another plunge; but the next moment all again is an interminable line of careering waters. Happy for the cruiser in untried reef-regions, if the surging waves continue to mark the line of reef; for a treacherous quiet sometimes intervenes, which seems to be evidence of deep waters ahead, and the unsuspecting craft dashes onward; but soon it is grinding over the coral masses, then thumping heavily at short intervals, and, in a few moments more, is landed helpless on the coral reef. The heavier billows, as they roll by a vessel in such a plight—the author's experience attesting—have a way of lifting it and then letting it drop with all its weight against the bottom, and hence, unless prompt escape is in some way secured, the assaulting waves gain speedy possession, and soon after make complete the work of destruction. At low tide the breakers often cease, or nearly so. But the reef for the most part is then in full view, and, with a good look-out aloft, favourable winds, and plenty of daylight, navigation is comparatively safe.

Some idea of the features of a tropical island thus bordered may be derived from the following sketch. The reef to the right is observed to fringe the shore, making a simple broad platform, as an extension, apparently, of the dry land. To the left there is the same coral platform at the surface, but it is divided by a channel into an inner and an outer reef—a *fringing* and a *barrier* reef, as these two parts are called. At a single place the sea is faced by a cliff; and here, owing to the boldness of the shores and depth of waters, the reef is wanting. The barrier reef at one point has a passage through it, which is an opening to a harbour; and many such harbours exist about coral-girt islands.

While some islands have only narrow fringing reefs, others are almost or quite surrounded by the distant barrier, which stands off like an artificial mole to protect the land from an encroaching ocean. The barrier is occasionally ten or fifteen miles from the land, and incloses not only one, but at times several, high islands. From reefs of this large size, there are all possible variations down to the simple fringing platform.

The inner channel is sometimes barely deep enough at low tide for canoes, or for long distances may be wanting entirely.



HIGH ISLAND WITH BARRIER AND FRINGING REEFS.

Then, again, it is a narrow intricate passage, obstructed by knolls or patches of coral, rendering the navigation dangerous. Again, it is for miles in length an open sea, in which ships find room to beat against a head wind with a depth of ten, twenty, or even thirty fathoms. Yet hidden reefs make caution necessary. Patches of growing corals, from a few square feet to many square miles in extent, are met with over the broad area inclosed by these distant barriers.

These varieties of form and position are well exemplified in a single group of islands—the Feejees; and the reader is referred to the chart of this Archipelago at the close of this volume.

Near the middle of the chart is the island *Goro;* its shores, excepting the western, are bordered by a fringing reef. The island *Angau*, south of Goro, is incircled by a coral breakwater, which on the southern and western sides runs far from the shores, and is a proper barrier reef, while on the eastern

side, the safe reef is attached to the coast and is a fringing reef. From these examples we perceive the close relation of barrier and fringing reefs. While a reef is sometimes quite incircling, in other instances it is interrupted, or wholly wanting, along certain shores; and occasionally it may be confined to a single point of an island.

Above Angau lies *Nairai;* although a smaller island than Angau, the barrier reef is of greater extent, and stretches off far from the shores. To the eastward of Nairai are *Vatu Rera*, *Chichia*, and *Naiau*, other examples of islands fringed around with narrow reefs. *Lakemba*, a little more to the southward, is also incircled with coral; but on the east side the reef is a distant barrier. In *Aiva*, immediately south of Lakemba, the same structure is exemplified; but the coral ring is singularly large for the little spots of land it incloses. The *Argo Reef*, east of Lakemba, is a still larger barrier, incircling two points of rock called Bacon's Isles. It is actually a large lagoon island, twenty miles long, with some coral islets in the lagoon, and two of basaltic constitution, of which the largest is only a mile in diameter. Aiva and Lakemba are in fact other lagoon islands, in which the rocky islands of the interior bear a larger proportion to the whole area. The same view is further illustrated by comparing the Argo reef with Nairai, Angau, or Moala: these cases differ only in the greater or less distance of the reef from the shores and the extent of the inclosed land.

Passing to the large islands *Vanua Levu* and *Viti Levu*, we observe the same peculiarities illustrated on a much grander scale. Along the southern shores of Viti Levu, the coral reef lies close against the coast; and the same is seen on the east side and north extremity of Vanua Levu. But on the west side of these islands, this reef stretches far off from the land, and in some parts is even twenty-five miles distant, with a broad sea within. This sea, however, is obstructed by reefs, and along the shores there are proper fringing reefs.

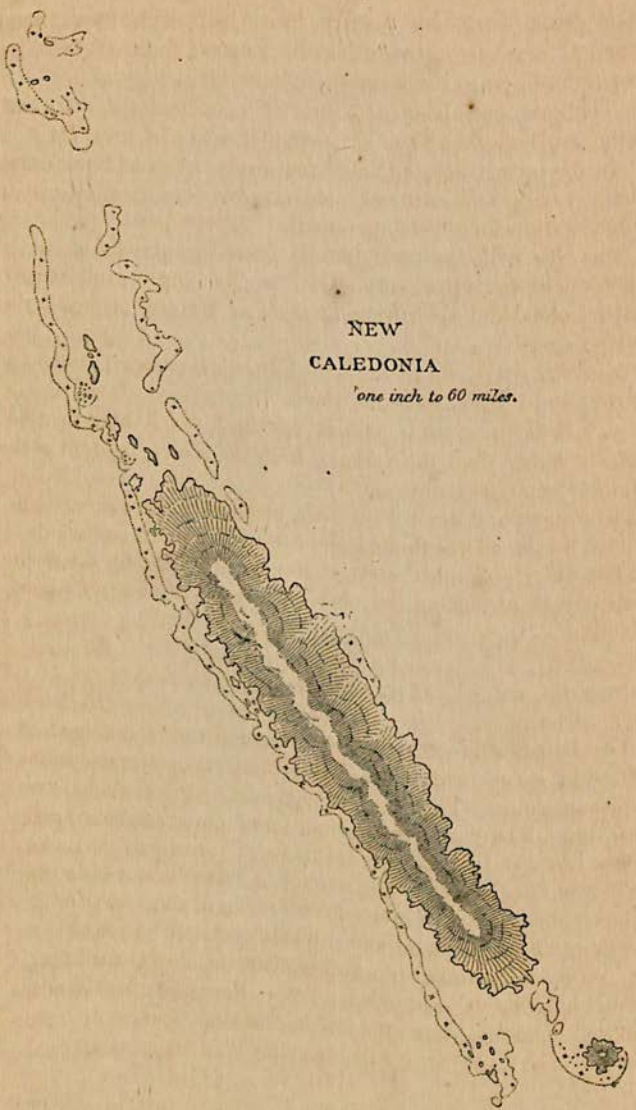
The forms of incircling reefs depend evidently to a great extent on that of the land they inclose. That this is the case

even in the Argo reef, and such other examples as offer now but a single rock above the surface of the inclosed lagoon, we shall endeavour to make apparent, if not already so, when the cause of the forms of coral islands is under discussion. Yet it is also evident that this correspondence is not exact, for many parts of the shores, and sometimes more than half the coasts, may be exposed to the sea, while other portions are protected by a wide barrier.

In recapitulation, we remark, that reefs around islands may be (1) entirely incircling; or they may be (2) confined to a larger or a smaller portion of the coast, either continuous or interrupted; they may (3) constitute throughout a distant barrier; or (4) the reef may be fringing in one part and a barrier in another; or (5) it may be fringing alone: the barrier may be (6) at a great distance from the shores, with a wide sea within, or (7) it may so unite to the fringing reef that the channel between will hardly float a canoe. These points are sustained by all reef regions.

It is to be noted that the fringing and barrier reefs here pointed out are not the whole of the coral reef; they are only the portions that have been built up to the water's level. Between them, and also outside of all, there are the submerged coral banks which are continuous with the higher portions, and all together make up the coral reef-ground of an island.

A wide difference in the extent of reef-grounds follows from the above-mentioned facts. On some coasts there are only scattered groups of corals, or rising knolls, or mere points of emerged coral rock; but again, as, for example, west of the two large Feejee Islands, there may be three thousand square miles of continuous reef-ground, occupied with coral patches and intermediate channels or seas. The inclosing barrier off Vanua Levu alone is more than one hundred miles long. The Exploring Isles, in the eastern part of the Feejee group, have a barrier eighty miles in circuit. New Caledonia has a reef along its whole western shores, a distance of two hundred and fifty miles, and it extends one hundred and fifty miles further north, adding this much to the length of the island.


NEW
CALEDONIA
one inch to 60 miles.

The great Australian barrier forms a broken line, twelve hundred and fifty miles in length, lying off the coast from the Northern Cape to the tropical circle.

The seas outside of the lines of coral reef are often unfathomable within a short distance of the line of breakers.

In the further description of reef-grounds, or reef-formations, there are several distinct subjects for consideration, as is obvious from the preceding remarks. These are—

1. *Outer reefs*, or reefs formed from the growth of corals exposed to the open seas. Of this character are all proper barrier reefs, and such fringing reefs as are unprotected by a barrier.

2. *Inner reefs*, or reefs formed in quiet water between a barrier and the shores of an island.

3. *Channels*, or *seas within barriers*, which may receive detritus either from the reefs, or from the shores, or from both of these sources combined.

4. *Beaches* and *beach formations*, produced by coral accumulations on the shores through the action of the sea and winds.

The outer and inner reefs, channels, and beaches, act each their part in producing the coral formations in progress about islands.

II. OUTER REEFS.

The barrier and other outer reefs are always submerged at high tide, except where elevated at surface by accumulations of beach sands. The level is generally that of about one-third tide. The coral rock is built up by the agencies at work to this level, and hence the existence of the broad platform-like top of the barrier. The surface is however not even, for there are many pools of water over it, even at the lowest tides, especially toward its outer limits, where corals of various kinds are growing luxuriantly, with fit associates of shells, star-fishes, echini, holothurias with their large flower-bearing heads, sponges, corallines and sea-weeds, making scenes of rare beauty. The growing corals are, however, most abundant

along the outer margin of the reef, and in the adjoining shallow seas. Here they grow in profusion ; but yet the eager lover of coral landscapes will be often disappointed by finding among the crowded plantations extensive areas of coral sand.

The outer margin of the reef receives the plunging waves, and under this action, and the consequent unequal growth of the corals, the outline is very irregular, being often deeply cut into, and hence having sometimes long channels that give entrance to the surging tide, and to the currents that flow back in preparation for the next breaker. From it, seaward, the depth of water usually sinks off rapidly from three to six fathoms, and then falls away more gradually for many rods, or it may be some hundreds of yards; over the bottom in these shallow waters are spread out the coral plantations, down to a depth of 80 or 100 feet. Finally there is a rather abrupt descent to depths beyond the reach of an ordinary sounding-lead. The great difference in the rapidity with which the water deepens depends chiefly on the varied character of submarine slopes. Shallow waters may extend out for miles, especially off the prominent points or angles ; but it is more common to meet with the opposite extreme—great depths within a few hundred feet.

The outer reef or coral platform is generally a little the highest at its seaward margin, owing partly to the growth of ordinary corals and other species on this part, and also to the accumulations which naturally would there be piled up by the waves and become cemented. This part is therefore first laid bare by the retreating tide ; and though a tempting place for a ramble, it is often a dangerous place on account of the heavy breakers. There is not only greater height, but often also a remarkably smooth surface to the reef-rock, looking as if water-worn, and frequently a blotching of the rock with various shades of pink and purple. These colours and the smoothness, as observed by Chamisso, are due to incrusting Nullipores; and to the same calcareous sea-weeds, as Darwin first observed, is often owing the increased height. The material of the incrusting plant is more solid than ordinary

coral, for it is without a pore; and layer is added to layer until it has considerable thickness. It is thus an important protection to the reef against the wash of the waters.

Darwin states that on Keeling's Island, the Nullipore bed has a thickness of two or three feet and a breadth of twenty feet. Nullipores are abundant on the Paumotu reefs. Still, they are not essential to the formation or protection of an outer reef, and are not always present; the outer margin is higher than the rest of the reef when they are absent.

The Nullipores are not alone on this outer edge, for there are always sprigs of Madrepores, small Astræas, and some other corals, lodged in the cavities, with many echini, starfishes and sea-anemones, besides barnacles and serpulas; and fish of many colours dart in and out of the numerous recesses.

Outer reefs are far more liable than the inner to become covered with accumulations of coral fragments and sand, through the force and inward movement of the waves. The *débris* gathered up by the waters finds a lodgment some distance back from the margin—it may be one or two hundred feet, or as many yards, and gradually increases, until in many instances dry land is formed, and an islet covered with vegetation appears. Such effects are confined chiefly to the reef on the sides open to the prevailing wind, and the final result, a green islet, is not of common occurrence. But occasionally the reef for miles has become changed from the coral bank, bare at low or middle tide, to habitable land, and makes literally, as at Bolabola, a green belt to the island of volcanic rocks and lofty hills within. The causes and the result are much the same as in a coral island, and the steps in the processare more particularly described further on, where treating of atolls.

The rock of the outer reef, wherever broken, exhibits usually a compact texture. In some parts it consists of coral fragments, rounded or angular, of quite large size, firmly cemented. Other portions are a finer coral breccia or conglomerate. Still others, more common, are solid white limestones,

as impalpable and homogeneous in texture as the old limestones of our continents. There are also other regions where the corals in the rock retain the original position of growth. But the rock in general consists of the *débris* of the coral fields, consolidated by a calcareous cement; and the great abundance of the finer variety of rock indicates that much of it has originated from coral sand or mud. Wherever broken, it usually presents the character here described, a texture indicating a detrital or conglomeritic origin. Such a reef-rock is formed in the midst of the waves; and to this fact it owes many of its peculiarities. Reef-rocks made of corals in the position of growth are formed about the outer reefs wherever the corals grow undisturbed.

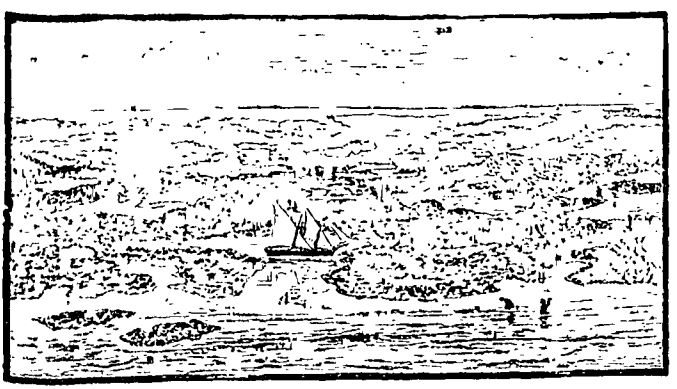
Besides corals, the shells of the seas contribute to it, and it sometimes contains them as fossils, along with bones of fishes, exuvia of crabs, spines and fragments of echini, orbitolites (disc-shaped foraminifers), and other remains of organic life inhabiting reef-grounds.

III. FORMATIONS IN THE SEA OUTSIDE OF THE BARRIER REEFS.

While barrier reefs are mostly made up of coarse coral material, owing to the rough action of the waves, the region immediately outside of the breakers, where of much width, is, to a depth of 100 feet, one of growing patches of coral and extended surfaces of coral sands.

Isolated islets of reef-rock are not however of common occurrence in the middle Pacific, though occurring in large groups like the Feejees. They are most likely to occur where there are great regions of shallow water extending outward from the barrier, and where the tides are not heavy or there is partial protection from them. In some seas, such isolated patches are shaped somewhat like a great mushroom—having a narrow trunk or column below, supporting a broad shelf of reef above. Mr. J. A. Whipple, in his Journal, referred to on page 99, figures and describes one of these "coral heads" standing in water fifty feet deep, near Turk's Island. Its trunk, which made up

two-thirds of its height (or of the fifty feet), was only fifteen feet in diameter along its upper half; and it supported above a great tabular mass one hundred feet in diameter, whose top was bare at low tide. The tide at this place is but two feet, and this is favourable to the preservation of such top-heavy structures. In many places, he says, these tops have joined together, leaving arches between them; and in some parts of the reef-region such united coral-heads cover acres in extent, being joined together above and supported by their pillars. A case is reported of a whale having gone through one of these under



THE LIXO CORAL REEF, ABROLHOS.

passages after being struck with a harpoon. Mr. Whipple also states that there are cavernous recesses in some of these heads, some that are 200 to 300 feet across; and "when there is a heavy swell on, the water is one entire sheet of white foam, caused by its being forced through them and the air entering as the heavy sea recedes from them."

Professor C. F. Hartt, in his "Geology, &c., of Brazil" (1870), describes very similar coral-heads in his account of the reefs of the Abrolhos, and represents a scene of coral-head tops in a sketch, of which the preceding is a copy. Professor Hartt

speaks of it as giving simply a general view of the region without any attempt at accuracy of position. The patches of reef in the view are of this coral-head kind, though not all as slenderly supported as that above described. A vessel is represented passing through a passage between two of them. Prof. Hartt, after describing the fringing reefs of the Abrolhos, gives the following account of the outside coral formations (p. 199). "Corals grow over the bottom in small patches, *in the open sea*, and, without spreading much, often rise to a height of forty or fifty or more feet, like towers, and sometimes attain the level of low water, forming what are called on the Brazilian coast *chapeirões* (signifying *big hats*). At the top these are usually very irregular, and sometimes spread out like mushrooms, or, as the fishermen say, like umbrellas. Some of these chapeirões are only a few feet in diameter. A few miles to the eastward of the Abrolhos is an area, with a length of nine to ten and in some places a breadth of four miles, over which these structures grow abundantly, forming the well-known Parcel dos Abrolhos, on which so many vessels have been wrecked." "Among these chapeirões I measured a depth of sixteen to twenty metres, and once, while becalmed, I found twenty metres alongside of one and three metres on top. They are rarely laid bare by the tide. They do not coalesce here to form large reefs as they do to the west of the islands. . . . Sometimes vessels striking heavily on small chapeirões, break them off and escape without injury, as has been remarked by Mouchez. At other times a vessel may run upon one and stick fast by the middle of the keel, to the amazement of the captain, who finds deep water all around, the vessel being perched on the chapeirões like a weather-cock on the top of a tower."

"In the northern part of the Parcel the chapeirões so closely unite as to form an immense reef, which has grown upward to a level a little above low water, and is quite uncovered at low tide." "The north-eastern part of the reef is called the Recife do Lixo, that is, Reef of the *Lixo*, a shark-like Ray which is furnished with large crushing teeth and frequents the reef in search of shell-fish."

The rock of the submerged coral-heads is but a loose aggregation of corals in the position of growth, except probably in their lower portion, where the open spaces may be filled with sand and fragments and all cemented together.

The deposits of sand or coral mud over the bottom of the seas outside of barrier reefs are sometimes of great extent. These sands are the fine detritus which the return flow of the breaker bears seaward; and, in still deeper water, the deposits should be mainly of the finest calcareous sand or mud—fit material for impalpable compact limestones. The waters outside of the reef, especially when moved by heavy tidal currents or storms, are often milky with the coral sand; and while the coarser sand is dropped near the shores, the finer may be carried for miles and distributed far out to sea. As Major Hunt, in his observations on the Florida Reefs remarks, this "white water" is one of the signs of proximity to a coral reef. After storms, the white coral material subsides and the waters become clear again.

Mr. Jukes, who made special examinations of the Australian reef region, and others in that vicinity, in H.M.S. *Fly*, states that in the deeper waters outside of the great barrier, "and in all the neighbouring East India seas, from Torres Straits, north of Australia, to the Straits of Malacca, wherever the bottom was brought up by the lead, it proved to be a very fine-grained, impalpable, pale olive-green mud, wholly soluble in dilute hydrochloric acid, and therefore essentially carbonate of lime. The substance, when dried, looked much like chalk, excepting in its greener tinge. How far this calcareous matter may be due to foraminifers, rather than corals, is not known."

Since the tidal waves on any coast that is gradually shallowing have a landward propelling power, the coral sands are mostly gathered about the reef, and generally are not to any great extent lost in the depths of the ocean. The great oceanic currents, like that of the Gulf Stream, might bear away the lighter material for long distances, if it swept with full strength over the shore reefs; but it is generally true that such currents are little felt close in shore. Notwithstanding the proximity of

the Florida reefs, and the strength of the Gulf Stream in the channel between the Keys and Florida, the adjoining sea-bottom consists mainly of common mud, with relics of deep-water life, and only sparingly of coral debris. According to Mr. L. F. de Pourtales, between twelve fathoms and one hundred, in the Florida channel, outside of the reef, coral fragments occur, but are rare; dead specimens of Cladocora and Oculina occur to a depth of about 50 fathoms. But on the other side of the channel, "along the Salt Key Bank, dead corals were dredged up in 315 fathoms; but this is at the foot of a very steep slope washed by the edge of the Gulf Stream; which is much better defined here than on the Florida side." The bottom, in the Florida channel, of 100 fathoms, is a rocky plateau, and outside of 200 fathoms, a mud full of foraminifers, *Globigerina mud*, as it is called from the species characterising it; and yet this channel is situated beneath the Gulf Stream and close by the Florida reefs. The facts seem to show that in most regions the reefs contribute little calcareous matter to the deep ocean. This may be otherwise over the bottom, of comparatively little depth, of a great Archipelago like that of the East Indies.

IV. INNER REEFS.

In the still waters of the inner channels or lagoons, when of large extent, we find corals growing in their greatest perfection, and the richest views are presented to the explorer of coral scenery. There are many regions—in the Feejees, examples are common—where a remote barrier incloses as pure a sea as the ocean beyond; and the greatest agitation is only such as the wind may excite on a narrow lake or channel. This condition gives rise to some important peculiarities of structure in the inner reefs, in which the inner margin of the barrier reef participates.

In the general appearance of the surface, the inner generally much resemble the outer reefs. They are nearly flat, and though mostly bare of life, and much covered with coral sand,

there are seldom any large accumulations of coral debris. The margin is generally less abrupt; yet there is every variety of slope, from the gradually inclined bed of corals to the bluff declivity with its clinging clumps. In different parts, there are many portions still under water at the lowest tides; and here (as well as upon the outer banks) fine fishing sport is afforded the natives, who wade out at ebb tide with spears, pronged sticks, and nets, to supply themselves with food. The lover of the marvellous may find abundant gratification by joining in such a ramble; for, besides living corals, there are myriads of other beings which science alone has named, of various beautiful forms and colours, as becomes the inhabitants of a coral world.

Between the large reefs, which spread a broad surface, at the water's edge, of lifeless coral rock, sometimes of great extent, there are other patches, still submerged, that are covered with growing corals throughout. They are of different elevations under the water's surface; and though at times but a few yards in breadth, there is often alongside of them a depth of many fathoms. The mushroom shape described above is common among them; and a ship striking one with her keel may crush it and glide on. More frequently, they are at bottom like the solid reef above described, and the contest is more likely to be fatal to the vessel than to the coral patch. In a passage between two reefs near Tongatabu, called the Astrolabe channel, the sloop of war *Vincennes* ran on a coral patch, which had been laid down as a reef. It stopped the ship for a moment, but broke away under her: and in the survey of the passage afterward, says Captain Wilkes, "no shoal was found in the place where the ship had struck, and we had the satisfaction of knowing that we had destroyed it without injury to the vessel." Corals grow over these patches, as in the shallow waters about other reefs; and, as elsewhere, there are deep cavities among the congregated corals, in which a lead will sometimes sink to a depth of many feet, or even fathoms. These holes about growing reefs often give much annoyance to the boat which may venture to anchor upon them; and in many

an instance diving is found to be the only resource left for freeing the foul anchor.

The margins of the reefs in and about the inner channels are often luxuriant with magnificent corals quite to the edge so that while the reef is elsewhere solid rock to its very top, here at the margin it is alive and may be said literally to be growing.

The rock of the inner reefs seldom consists of rolled or broken fragments of coral like a large part of that of the outer reef. It is often made of dead corals, standing to a great extent as they grew; yet it is generally compact and firm in texture. The cavities among the branches and masses gradually become filled with coral sand, and the whole is finally cemented and so made solid. At Tongatabu and among the Feejee Islands, reefs thus formed of corals standing in their growing positions are common. Though now mere dead rock, and exceedingly firm and compact, the limits of the several constituent coral masses may be distinctly made out. Some individual specimens of Porites in the rock of the inner reef of Tongatabu are twenty-five feet in diameter; and Astræas and Mæandrinas, both there and in the Feejees, measure twelve to fifteen feet. These corals, when growing beneath the water, form, as has been stated, solid hemispheres, or rounded hillocks; but on reaching the surface, the top dies, and enlargement takes place only on the sides; and in this manner the hemisphere is finally changed to a broad cylinder with a flat top. This was the condition of the Astræas and Porites in the reef-rock referred to. Such a platform looks like a Cyclopean pavement, except that the calcareous cementing material, filling in between the huge masses, is more solid than in any work of art: it even exceeds in compactness the corals themselves. Other portions of reefs consist of *branching* corals, with the intervals filled in by sand and small fragments; for even in the stiller waters fragments are to some extent produced. A rock of this kind is often used for buildings and for walls on the island of Oahu. It consists mainly of Porites, and in many parts is still cavernous, or but imperfectly cemented.

There is also to be found about inner reefs, over large areas, the solid white limestone already described, showing internally no evidence of its coral origin, and containing rarely a shell or other imbedded fossil. It is a result of the consolidation of the fine coral sand or mud that is made and accumulated through the action of the light waves that work over the inner reefs. It has been said that large regions of barren sands or mud occur among the patches of growing corals, and these would give origin to this compact limestone.

The formation of the inner reefs goes on at a less rapid rate than that of the outer, because the process depends on the growth of the corals with comparatively little aid from the action of the waves. Moreover, as is explained more particularly in another place, impure or fresh waters and currents often operate to destroy the living corals, or retard their progress.

Owing to the last-mentioned cause, the inner reefs are not usually joined directly to the beach. They stand off a little, separated by an interval of shallow water. At Mathuata, in the Feejees, however, the reef extends quite up; and it is the more remarkable as the coast is flat, the site of a Feejee village, and a mile or two back stands a high bluff. On an island off this part of Vanua Lebu there is another example of this fact, and many more might be cited. In such cases, however, there is evidence that the shores upon which the corals grew were bare rocks, instead of moving beach-sands.

From these descriptions it appears that the main distinction between the inner and outer reefs consists in the less fragmentary character of the rock in the former case, the less frequent accumulations of debris on their upper surface, and the more varied features and slopes of the margin. Moreover, the Nullipores, which seem to flourish best in the breakers, are here but sparingly met with.

The variety of coral zoophytes is also greater in the stiller water, and there are species peculiar to the different regions.

V. CHANNELS AMONG REEFS.

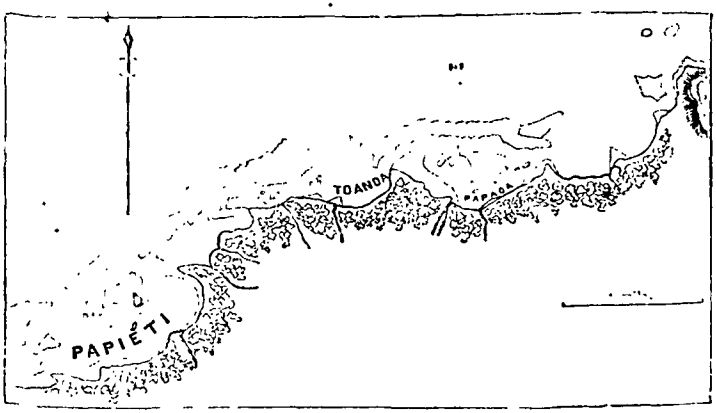
To complete this review of the general appearance and constitution of reef formations, it remains to add some particulars respecting the channels which intervene between coral patches, or separate them from the shores of an island, and also to describe the coral accumulations forming beaches.

The reef of Australia has been instanced as affording an example of one of the larger reef-channels, varying from twenty to sixty miles in width, and as many fathoms in depth. Its average distance from the land is twenty to thirty miles, and the ordinary depth ten to twenty-five fathoms; but toward the southern end, where the channel is widest, the depth exceeds sixty fathoms. "The new Caledonia barrier reefs, 400 miles in length," says Darwin, "seldom approach within eight miles of the shore." The reefs west of the large Feejee Islands are another remarkable example, the reef-grounds being in some parts twenty-five miles wide, and the waters within the barrier, where sounded, twelve to forty fathoms in depth. The barrier in this instance may be from a few hundred yards to half a mile in width; and some of the inner patches are of the same extent; but by far the larger part of the reef-ground is covered with deep waters, mostly blue like the ocean, and as clear and pure. In the course of the cruise of the Wilkes Exploring Expedition, the sloop of war *Peacock* sailed along the west coast of both Viti Lebu and Vanua Lebu, within the inner reefs, a distance exceeding two hundred miles.

The island of Tahiti, on its northern side, presents a good illustration of a narrow channel, and at the same time one that exhibits the usual broken or interrupted character of reefs. This is seen in the following cut, in which the reefs, both fringing and barrier, are the parts inclosed by dotted lines. The outer reef extends half to two-thirds of a mile from the shore. Within it, between Papieti and Matavai, there is an irregular ship channel, varying from three to twenty fathoms in depth. Occasionally it enlarges into har-

bours; and in other parts it is very intricate, though throughout navigable by large vessels. The island of Upolu, of the Samoan group, is bordered by a reef nearly a mile wide on part of its northern shore; but the waters within are too shallow for a canoe at low tide; and therefore, notwithstanding its extent, the reef is rather a fringing than a barrier reef. Within the green belt that incircles Bolabola (p. 109) there is a large and deep channel navigable by ships.

Beneath these channels lies, in general, the coral rock of the reef-region—the inferior part of the great reef formation whose



CORAL REEFS OFF THE NORTH SHORE OF TAHITI.

upper portions constitute the so-called barrier and fringing reefs. The rock would necessarily resemble that of the inner reefs already described; but there should be a larger proportion of the white compact limestone made from the fine coral sands carried off from the higher reefs by the currents.

Yet the bottoms of these channels are not always made up of calcareous or coral sands and fragments; for the volcanic or basaltic lands they adjoin are a source of ordinary mud; and the river courses of the land and the tidal currents of the sea will often determine the nature of the bottom, or may cause in it alternate variations.

At Upolu the white coral sands of the reefs (or in more general terms the reef debris) form the bottom. In some places this coral material had the consistence of mud, and it was seldom observed to be covered with coarse material; there were some small patches of coral over it, and here and there a growing mass of Porites. The fresh waters of the shores do not flow over these wide reefs, as there is no proper inner channel, and there is consequently no shore detritus mingled with the reef debris.

At Tahiti, the sounding lead, where dropped in the channels, usually brought up sand, shells, and fragments of coral. At Tongatabu, the bottom where the *Peacock* anchored was a greyish blue calcareous mud, appearing as plastic as common clay; it consisted solely of comminuted corals and shells, with colouring matter probably from vegetable and animal decomposition.

But to the west of the larger Feejee islands, in the channels near the land, soundings commonly indicated a bottom of mud made from the material of the rocks of the mountains, and the same was frequently brought up with our dredges. On the north side of Vanua Lebu, a stream had so filled with its detritus the wide channel into which it empties, that for a mile the depth is but two to three fathoms, although elsewhere the depth is mostly from twelve to twenty fathoms; and at least half a dozen square miles of land had been added to the shores from this source. Though due principally to shore material, the reefs have probably added somewhat to these accumulations; yet little coral sand could be detected in the mud by the eye, and the proportion is certainly very small. In many places where the ships of the Wilkes Exploring Expedition anchored, having the reef not more than five hundred yards from the ship, the material of the bottom was wholly mud from the land, as much so as if there were no corals or shells within many miles.

When the materials from both sources, the shore and the reef, are mingled, the proportion will necessarily depend on the proximity to the mouths of streams, the breadth of the inner waters or channels, and the direction and force of the currents.

These tidal currents often have great strength, and are much modified and increased in force at certain places, or diminished in others, by the position of the reef with reference to the land. Sweeping on, they carry off the coral debris from some regions to others distant; and again they bear along and distribute only the shore detritus. It is thus seen that the same region may differ widely in its adjacent parts, and seemingly afford evidence in one place that there is no coral near, and in another no high land, although either is within a few rods, or even close alongside.

The extent of the land in proportion to the reef will have an obvious effect upon the character of the channel or lagoon depositions. When the island stands, like one of Bacon's Isles in the Feejees, as a mere point of rock in a wide sea inclosed by a distant barrier, the streams of the land are small and their detritus quite limited in amount. In such a case, the reef, and the growing patches scattered over the lagoon, are the sources of nearly all the material that is accumulated upon the bottom.

The bottom between the inner reefs within the great Australian barrier, according to Jukes, as brought up by the dredge from depths of fifteen to twenty fathoms, often resembled the unconsolidated mass of a shelly or coralline limestone. At other times it consisted very largely of the small disk-shaped foraminifers called Orbitolites, closely allied in form and nature to the Nummulites of the Tertiary; and they seemed in some places to make up the whole sand of the beaches, both of the coral islets and of the neighbouring Australian shores.

The facts show that the rock formed in such channels may be of all the kinds that occur in reef regions—coral and shell conglomerates, compact impalpable limestones, limestones full of Orbitolites, or containing, as well, remains of other species of the seas, and also rocks made of the clay, mud, sand, or pebbles of the mountains or high lands adjoining.

VI. BEACH SAND-ROCK.

Besides the ordinary coral rock, there are also beach formations made of coral sands, worn shells, &c., thrown up by the tides and waves. Their mode of formation is like that of any sea-beach. The material is mostly like common sand in fineness, but often much coarser. When the beach is fronted by a distant barrier to shield it from the force of the waves, the material is usually sand and small pebbles; but if the reef is narrow, so that the sea breaks over it with full force, it may consist even of cobble stones, as on any other shore, and include also huge masses of coral rock.

These deposits become cemented by being alternately moistened and dried, through the action of the recurring tides and the wash of the sea on the shores. The waters take up some carbonate of lime, and this is deposited and hardens among the particles on the evaporation of the moisture at the retreat of the tides. In some places the grains are loosely coherent, and seem to be united only by the few points in contact; and with a little care the calcareous coating which caused the union may be distinctly traced out. In other cases, the sand has been consolidated into a solid limestone rock, the interstices having been filled till a compact mass was formed. Generally even the most solid varieties show evidence of a sand origin, and in this they differ from the reef rock. The pebbly beds produce a pudding stone of coral.

In most localities the rock is an oolite or oolitic limestone. The grains become coated by the agglutinating carbonate of lime, and each enlarges thus into a minute sphere—a spherical concretion; and the aggregation of these concretions makes the oolite. The grains are usually much smaller than the roe of most fishes, a resemblance which is alluded to in the name, from the Greek *ωον, egg*.

These beach deposits consist of regular layers, commonly from a few inches to a foot in thickness, and are generally consolidated up to a line a little above high-tide mark. In all

instances observed, the layers dip at an angle of six to eight degrees down the beach. This dip is nothing but the slope of the beach itself, and arises from the circumstance that the sands are deposited by the incoming waves, or tides, on such a sloping surface. Tutuila and Upolu, in the Navigator group, and Oahu in the Hawaiian, afford many examples of these beach formations. At certain localities the beach sand-rock has been washed away after it was formed; and occasionally large masses or slabs have been uplifted by the sea and thrown high up on the beach.

Deposits of the same kind sometimes include detritus from the hills. Black basaltic pebbles are thus cemented by the white calcareous material, producing a rock of very singular appearance. Near Diamond Hill, on Oahu, is a good locality for observing the steps in its formation. Many of the pebbles of the beach are covered with a thin incrustation of carbonate of lime, appearing as if they had been dipped in milk, and others are actually cemented, yet so weakly that the fingers easily break them apart.

The lime in solution in waters washing over these coral shores is also at times deposited in the cavities or seams of the volcanic rocks; thus the cavities of a lava or basalt become filled with white calcareous kernels, and the cellular lava is changed into an amygdaloid. In large cavities, or caverns, it often forms stalactites or stalagmitic incrustations. Similar facts are stated by Mr. Darwin as observed on the shores of Ascension; and many interesting particulars are given respecting calcareous incrustations on coasts in his work on Volcanic Islands, some of which are cited further on. They were observed by the writer upon Madeira, in St. Jago, one of the Cape Verds, as well as among the volcanic islands of the Pacific.

Jukes speaks of the oolitic character of the beach sand-rock about islets connected with the Australian barrier, and states "that the fact that the rock was not consolidated under water was proved by nests of turtles' eggs being found imbedded in it, these evidently having been deposited by the animal when the sand was above water and still loose and incoherent."

VII. DRIFT SAND-ROCK.

Still another kind of beach formation is going on in some regions through the agency of the winds in connection with the sea. It occurs only on the windward side of islands when the reefs are narrow, and proceeds from the drifting of the sand into hillocks or ridges by the winds.

The drifts resemble ordinary sand-drifts, and are often quite extensive. On Oahu, they occur at intervals around the eastern shores, from the northern cape to Diamond Point, which forms the south cape of the island,—the part exposed to the trades; and they are in some places twenty to forty feet in height. They are most remarkable on the north cape, a prominent point exposed to the winds that blow occasionally from the westward, as well as to the regular trades. They also occur on Kauai, another of the Hawaiian Islands. But at Upolu (Samoa), where the protecting reefs are broad, the author met with no instance worthy of mention.

These sand-banks, through the agency of infiltrating waters, fresh or salt, become cemented into a sand-rock, more or less friable, which is frequently oolite. The rock consists of thin layers or laminæ, which are very distinct, and indicate, generally, every successive drift of sand which puffs of wind had added in the course of its formation: and where a heavier gale had blown off the top of a drift, and new accumulations again completed it, the whole history is distinctly displayed in the rock. Several catastrophes of this kind may be made out from the character of the lamination in the sand-bluffs on the north side of Oahu. Since their formation, this island has undergone an elevation of twenty-five or thirty feet; these hills, once on the shores, are now seventy feet above the level of the sea, and they face the water with a bluff front (due to degradation), in which the lamination is finely exposed to view. The layers are but a fraction of an inch; at one of the hills large slate-like slabs may be obtained; they have a sanded surface, but are so hard within as to clink under the hammer.

About cavities over the surface, the rock is usually very compact to a depth of half an inch or more, almost horny in texture, owing to the infiltration of lime from the waters often occupying them; but this is an exceptional variety of the rock. A particular description of these bluffs is given in the author's report on the geology of the Hawaiian Islands.

One of the most interesting facts observed in connection with these drift hills, is the absence of shells, and even of fragments of shells or corals sufficiently large to be referred to either of these sources. The material is sand, without organic remains, although situated on shores off which, within a hundred yards, there are shells and corals innumerable. The grinding action of the waves and winds reduces all the coral fragments and shells, by mutual trituration, to a fine beach sand.

Oolitic beds appear to be confined to the superficial formations of a reef, that is, to the beach and wind-drift accumulations. No example has come under the notice of the author of oolite constituting the foundation rock of a reef or island. It is possible that such beds might in some cases be the basement rocks to a considerable depth below; for a reef-island might subside so much more slowly than coral formations grow and accumulate, that a succession of beach-made beds would be produced even to a great thickness. Yet the probability is that the subsidence would sink the surface beneath the water, and put an end to beach and wind-drift work. The beach slope of 6° to 8° is an almost constant mark of beach-made beds.

VIII. THICKNESS OF REEFS.

We have considered in the preceding pages the peculiarities of form and structure characterising the reef formations bordering islands and continents, and their influence upon the inclosed land. Could we raise one of these coral-bound islands from the waves, we should find that the reefs stand upon the submarine slopes, like massy structures of artificial masonry; some forming a broad flat platform or shelf ranging around

the land, and others incircling it like vast ramparts, perhaps a hundred miles or more in circuit. The reefs that were near the water-line of the coast would be seen to have stood in the shallowest water, while the outer ramparts rested on the more deeply submerged slopes. Indeed, it is obvious that with a given slope to the declivity of the land, the thickness of the reef resting upon it may be directly determined, as it would be twice as great two hundred feet from the shore as at one hundred feet. The only difficulty, therefore, in correctly determining the depth or thickness of any given reef, arises from the uncertainty with regard to the submarine slope of the land. It is, however, admitted, as the result of extensive observation, that in general these slopes correspond nearly with those of the land above water. Mr. Darwin has thus estimated the thickness of the reefs of the Gambier group (p. 227) and some other Pacific islands, and he arrives at the conclusion, as his figures indicate, that some coral reefs, at their outer limits, are at least *two thousand feet* in thickness.

The mountain slopes of the islands of the Pacific, except when increased by degrading agents, do not exceed in angle twelve or fourteen degrees, and they are often but half this amount. The slopes of Mauna Kea and Mauna Loa, on the island of Hawaii, do not average over eight degrees. On the north side of Upolu, where the reefs are wide, the inclination is from three to six degrees. Throughout the Pacific, the *steeper* slopes of the mountains are due to agencies which cannot be shown to have affected the submarine slopes, excepting in cases of disruption of islands by forces below.

Assuming *eight* degrees as the mean inclination, we should have for the depth of reef (or water), one mile from the shore, 740 feet; or, assuming *five* degrees, 460 feet. Adopting the first estimate, the Gambier group would give for the outer reef a thickness of at least 1,750 feet; or with the second, 1,150 feet. The island of Tahiti (taking the north side for data) would give in the same manner 250 feet by the last estimate, which we judge to be most correct; Upolu, by the same estimate, 440 feet. The deduction for Upolu may be too large:

taking three degrees as the inclination, it gives 260 for the thickness at the outer margin. The results are sufficiently accurate to satisfy us of the great thickness of many barrier reefs.

These calculations, however, are liable to error from many sources. Very different results might generally be obtained from different sides of the same island; and the same group often contains islands without reefs, and others with reefs one or even several miles from the shores. But since we may show that the absence of a reef, or its limited extent, may be traced to some causes restricting or modifying its formation, it is obvious that the error would probably be on the side of too low an estimate.

Adjacent to the larger islands, such as those of Vanua Levu, and Australia, the error might be of the opposite kind; for the slopes of the land are of a more complex or irregular character than on the smaller islands. In the latter, they may be shown to belong generally to a single elevation of igneous origin, or, at the most, to two or three combined; while, in the former, they may pertain to different ranges of hills or mountains. For correct results in any instance, the land and its declivities should be carefully studied beforehand, and the system in its inclinations determined by observation. With regard to Tahiti and Upolu, information bearing upon this point was obtained, and the above conclusions may be received with much confidence. Many of the Feejee reefs, on the same principle, cannot be less than 2,000 feet in thickness.

IX. A GOOD WORD FOR CORAL REEFS.

All coral-bound coasts, and especially those of islands in mid ocean, derive great benefit from their reefs. The wide coral banks and the inclosed channels greatly enlarge the limits tributary to the lands they incircle. Besides being barriers against the ocean, they are dikes to detain the detritus of the hills. They stop the waters of the streams, and cause it to drop the

silt they were bearing off, and thus secure its addition to the land. They prevent, therefore, the waste which is constantly going on about islands without such barriers; for the ocean not only encroaches upon the unprotected shores of small islands, but carries off much of whatever the streams empty into it. The delta of Rewa, on Viti Lebu, resulting from the detritus accumulations of a large river, covers nearly sixty square miles. This is an extreme case in the Pacific, as few islands are so large, and consequently rivers of such magnitude are not common. But there is rarely a coral-girt island which has not at least some narrow plains from this source; and upon them the villages of the natives are usually situated. Around Tahiti these plains are from half a mile to two or three miles in width, and the cocoa-nut and bread-fruit groves are mostly confined to them.

The reefs also provide extensive fishing-grounds for the natives, and afford abundant fish, their main reliance in the way of animal food. They also supply large interior waters for practice in navigation and for safe communication between distant settlements. And the effect is evident in the spirit of maritime enterprise which characterises the islanders; for these circumstances have favoured the construction of large sail-canoes in which they venture beyond their own land, and often undertake voyages hundreds of miles in length. Communication between the Friendly Islanders and the Feejees has long been kept up by means of these large rudely-rigged sail-canoes.

Instead of a rock-bound coast, harbourless and thinly habitable, like St. Helena, in the tropics, and nearly all extra-tropical islands, the shores of these reef-bound lands are blooming to the very edge, and wide plains are spread out with bread-fruit and other tropical productions. Harbours, safe for scores of vessels, are also opened by the same means; and some islands number a dozen, when the unprotected shores would hardly have afforded a single good anchorage. Jukes remarks that the sea within the great Australian barrier is "one great natural harbour;" and this harbour is as long as from the extremity of Florida to Newfoundland.

Coral-reefs are sometimes viewed as only traps to surprise and wreck the unwary mariner; but whoever has visited the dreary prison-house, St. Helena, will have some appreciation of the benefits derived from the growing zoophytes.

But in addition to these general benefits, there are also contributions from the larger reef regions to the commerce of the world. Besides pearls, there is the *biche de mar* (called also *bêche de mer*, *sea-ginseng*, and in China, *tripang*), thousands of hundredweight of which annually enter the Chinese market from the reef-regions of the East Indies, Australia, and the seas to the north, including the Feejee Archipelago. This favourite material for Chinese dishes, either stews or soups, &c., is *dried holothuria*—large slug-like animals, called often *sea slugs*, and also *sea cucumbers*, from their form in the contracted state. They are not slugs, but are most nearly related to the echinus, though having a thick flexible skin, while the echinus has for its exterior a firm shell, armed about with spines. The largest are only nine or ten inches long when contracted; but they lengthen out sometimes to two feet or more. They live just under the sand in the shallow waters, with the head projecting and bearing a beautiful feathery rosette or flower which is branchial in nature. To fit them for exportation, the holothuria, of which half a dozen different kinds are taken, are slit open, boiled, and then dried, in which last state they look like "smoked sausages." Dr. S. Wells Williams says, in his "Middle Kingdom," that "when soaked in water, the material resembles pork rind, and is like that in taste when stewed." They are brought to China by the Malays from Macassar and elsewhere. There are also large drying-houses at the Feejees, and ships from America make their occasional visits to collect them, with the aid of the Feejees, and to dry and load up for China. The term *biche de mar*, and also the French form of it, *bêche de mer*, are corruptions of the Portuguese *bicho do mar*, which means *sea-worm*, or *sea-slug*.

II. STRUCTURE OF CORAL ISLANDS.

I. FORMS AND GENERAL FEATURES.

Coral islands resemble the reefs just described, except that a lake or lagoon is incircled instead of a mountainous islands. A narrow rim of coral reef, generally but a few hundred yards wide, stretches around the inclosed waters. In some parts the reef is so low that the waves are still dashing over it into the lagoon; in others it is verdant with the rich foliage of the tropics. The coral-made land, when highest, is seldom more than ten or twelve feet above high tide.

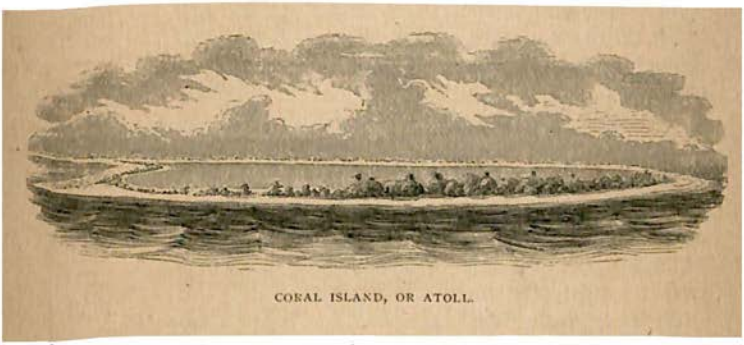
When first seen from the deck of a vessel, only a series of dark points is descried just above the horizon. Shortly after the points enlarge into the plumed tops of cocoa-nut-trees, and a line of green, interrupted at intervals, is traced along the water's surface. Approaching still nearer, the lake and its belt of verdure are spread out before the eye, and a scene of more interest can scarcely be imagined. The surf, beating loud and heavy along the margin of the reef, presents a strange contrast to the prospect beyond,—the white coral beach, the massy foliage of the grove, and the embosomed lake with its tiny islets. The colour of the lagoon water is often as blue as the ocean, although but ten or twenty fathoms deep; yet shades of green and yellow are intermingled, where patches of sand or coral-knolls are near the surface; and the green is a delicate apple shade, quite unlike the ordinary muddy tint of shallow waters.

The belt of verdure, though sometimes continuous around the lagoon, is usually broken into islets separated by varying intervals of bare reef; and through one or more of these intervals a ship-channel often exists opening into the lagoon. The larger coral islands are thus a string of islets along a line of reef.

These lagoon islands are called *atolls*, a word of Maldive origin. The king of the Maldives bears the high-sounding

title of "Ibrahim Sultan, King of the thirteen Atollons and twelve thousand Isles" (see page 153); which Capt. W. F. W. Owen, R.N., says is no exaggeration.

In the larger atolls, the waters within look like the ocean, and are similarly roughened by the wind, though not to the same extent. Standing on the north shore of the Raraka lagoon and looking south-west, nothing is seen but blue waters. Far in the distance to the right, and also to the left, a few faint dots are observed; and as the eye sweeps around in either direction, these dots gradually enlarge and pass into lines of verdure, and, finally, distinct groves near the observer. At Dean's Island, another of the Paumotus, and at some of the Carolines, the resemblance to the ocean is still more striking.



CORAL ISLAND, OR ATOLL.

The lagoon is in fact but a fragment of the ocean cut off by more or less perfect walls of coral reef-rock; and the reef is here and there surmounted by verdure, forming a series of islets.

In many of the smaller coral islands, the lagoon has lost its ocean character, and become a shallow lake, and the green islets of the margin have coalesced in some instances into a continous line of foliage. Traces may perhaps be still detected of the passage, or passages, over which the sea once communicated with the internal waters, though mostly concealed by the trees and shrubbery which have spread around and completed the belt of verdure. The coral island is now in its

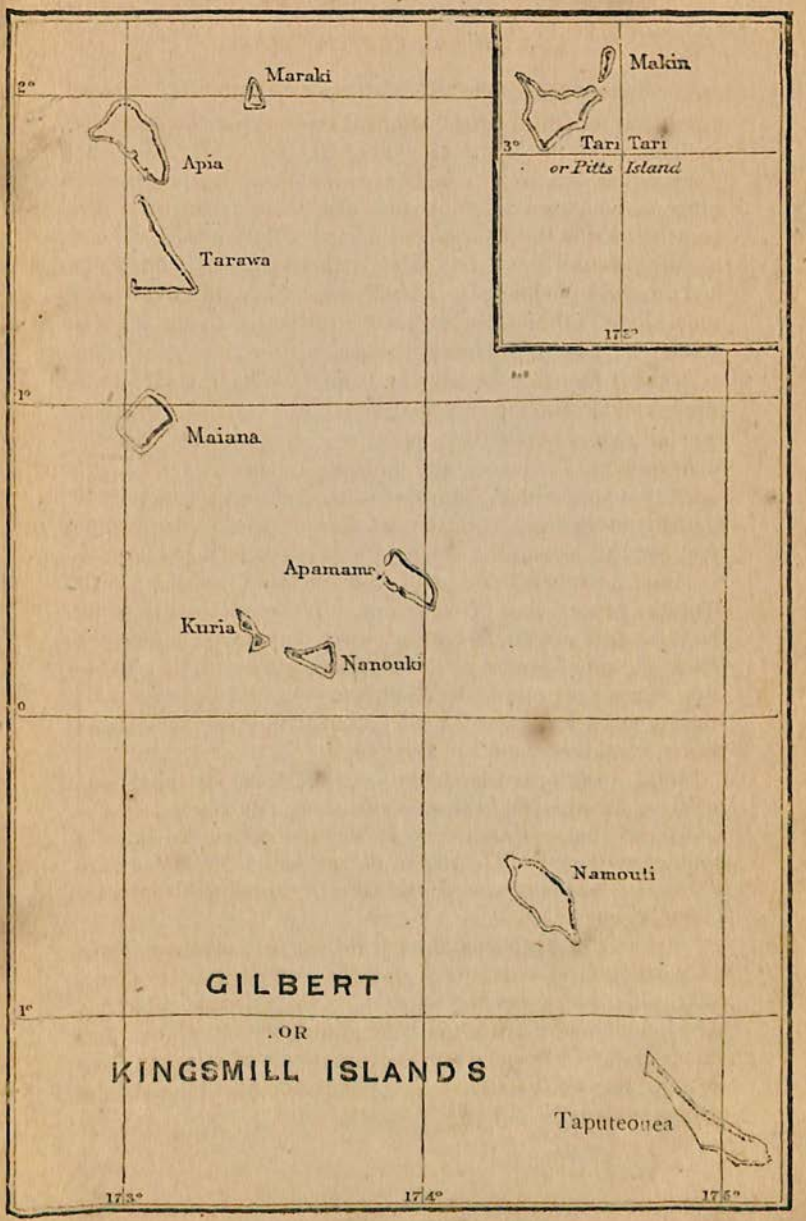
most finished state; the lake rests quietly within its circle of palms, hardly ruffled by the storms that madden the surrounding ocean.

From the islands with small lagoons, there is every variety in gradation down to those in which there is no trace of a lagoon. These simple banks of coral are the smallest of coral islands. In all the larger islands the windward side is the highest; and sometimes it is wooded and habitable throughout when the leeward reef is bare. The entrances to the lagoons are accordingly on the leeward side.

A single group of islands, the Gilbert or Kingsmill, affords good examples of the principal varieties. It is at once seen from these examples that atolls are *not annular*. In the southernmost, Tapateuea, the form is very narrow, the length being thirty-three miles, with the width of the southern portion scarcely exceeding six miles, and that of the northern more than one-half less. The emerged land is confined to one side, the eastern or windward, and consists of a series of islets upon the eastern line of coral reef. The western side is for the most part several feet under water, and there is hardly a proper lagoon. Sailing by the island, to windward, the patches of verdure, thus strung together, seem to rise out of a long white line of breakers, the sea surging violently against the unseen coral reef upon which they rest.

Nonouti, the next island north, is about twenty miles long by eight broad. The rim of land, though in fewer islets, is similar to that of Tapateuea in being confined to the reef fronting north-east. The reef of the opposite side, though bare of vegetation, stands near low-tide level, and the whole incloses a large lagoon.

Aranuka and Apamama, though smaller than Nonouti, have the same general character. Aranuka is triangular in shape, and has an islet on the western point or cape, which is quite prominent. Apamama differs from either of the preceding in having two narrow ship entrances to the lagoon, one through the north-western reef, and another through the south-western.


Maraki
Apia
Tarawa
Maiana
Apamama
Kuria
Nanouki
Namouti
GILBERT
OR
KINGSMILL ISLANDS
Taputeouea
Makin
Tari
or Pitts
Tari
Island
2°
1°
0
1°
3°
173°
174°
175°

Kuria is a remarkable double island, without a proper lagoon. It consists of two neighbouring groves, each about a square mile in extent, on adjacent patches of reef.

Maiana is quite regularly quadrangular, with an uninterrupted range of land on two of the four sides, and an exposed reef constituting the other two.

Tarawa consists of two sides of a triangle. The western reef is wanting, and the sea and lagoon have unbroken communication. In place of it, there are two to ten fathoms of water, and a bottom of coral sand. Small vessels may sail in almost anywhere on this side to good anchorage, and there is a passage for ships of the largest size. The depth within is greater than on the bar, and these inner waters obviously correspond to the lagoon of other islands.

Apaiang has much resemblance to Apamama in its forest border and lagoon. Moreover, there is a ship entrance through the south-western reef.

Marakei is one of the prettiest coral islands of the Pacific. The line of vegetation is unbroken. In a view from the mast-head it lies like a garland thrown upon the waters; the unpractised eye scarcely perceives the variation from a circular form, however great it may be. The grove is partially interrupted at one point, where there are indications of a former passage through the reef.

Tari-tari, lying to the south of Apia, is a large triangular atoll. It is wooded almost continuously on the side facing south-east, and has a few spots of verdure on the south-west, with three entrances to the extensive lagoon. The northern side is a naked reef throughout, scarcely apparent from a ship's deck, except by the long line of breakers. Makin, just north of Tari-tari, is a mere patch of coral reef without a lagoon.

We add a few more descriptions of Pacific islands, with figures reduced from the map of the Wilkes Expedition to a scale of four-tenths of an inch to a mile.

Taiara and Henuake (Figs. 1 and 2) are two small belts of foliage, somewhat similar to Maraki. Henuake possessed an additional charm in being tenanted only by birds; and they

were so tame that we took them from the trees as if they had been their flowers.



TAIARA.



HENUAKE, OR HONDEN.

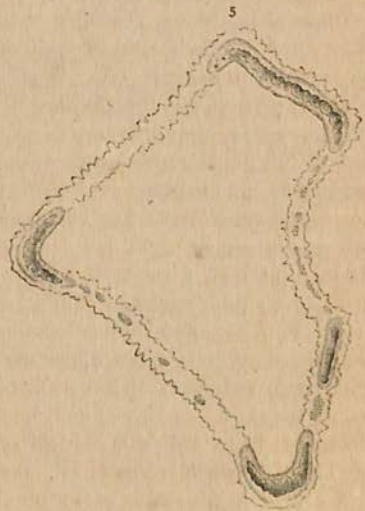
Jarvis's and Swain's Islands (Figs. 3 and 4) are of still smaller size, and have no lagoon. The surface of the former



JARVIS'S ISLAND.



SWAIN'S ISLAND.



FAKAAFO, OR BOWDITCH'S ISLAND.

is sandy, while the latter is densely covered with foliage. Both islands are a little depressed about the centre, a fact indicating that there was formerly a lagoon.

Fakaafo, or Bowditch (Fig. 5), 200 miles north of the Navigator Islands, is the type of a large part of coral islands. The bank of reef has only here and there emerged from the waves and become verdant; in other portions the reef is of the usual height,—that is, near low-tide level,—excepting a few spots elevated a little by the accumulation of sand.

The Paumotu Archipelago, the crowded cluster of coral islands east and north-east of Tahiti, is a most instructive study for the reader; and a map of these islands by the Wilkes Exploring Expedition, inserted in the Narrative of the Expedition, and also in the Hydrographical Atlas, will well repay close examination. Sailing among these islands, over eighty in number,—only four of which are over twelve feet high exclusive of the vegetation,—two or three are almost constantly in sight from the mast-head.

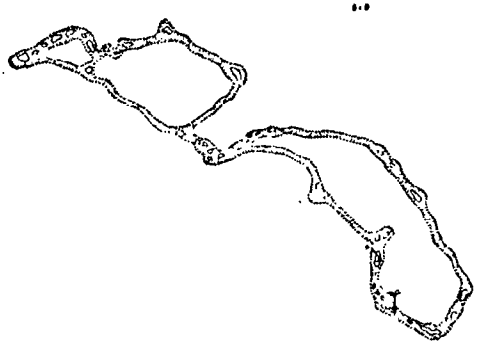
The small amount of habitable land on these reef-islands is one of their most peculiar features. Nearly the whole surface is water; and the land around the lagoon is but a narrow rim, the greater part of which is usually under water at high tide. This fact will be rendered more apparent from the following table, containing a statement of the sizes and areas of several islands, with the amount of habitable land. The measures are given in geographical miles.

	LENGTH.	GREATEST BREADTH.	AREA IN SQ. MILES.	HABITABLE PARTS IN SQ. MILES.
Carlshoff, Paumotus	27	13	200	10
Wolchonsky ,,	15	3	40	3
Raraka ,,	15	10	90	8
Manhii ,,	14	6½	50	9
Nairsa or Deans, Paumotus	50	19	1,000	16
Fakaafo, Union group	7½	4½	20	2½
Duke of Clarence ,,	8½	5½	27	2
Tapateuea, Kingsmills	33	6	60	6
Tarawa ,,	20	10	130	8
Nonouti ,,	22	9	125	7
Tari-tari ,,	18	11	110	4

The ten islands here enumerated have an aggregate area of 1,852 square miles, while the amount of actual dry habitable

land is but seventy-six miles, or less than one twenty-fourth. In the Caroline Archipelago the proportion of land is still smaller. Menchikoff atoll covers an area of 500 square miles, and includes hardly six square miles of wooded land. In the Marshall Islands the dry land is not over one-hundredth of the whole surface; while in the Pescadores the proportion of land to the whole area is about as 1 to 200.

The distribution of the land upon the reef is obvious from the sketches already given. It is seen, as long since remarked, that the windward side is, in general, the highest. It is also



MENCHIKOFF ATOLL ($\frac{1}{10}$ OF AN INCH TO A MILE)

apparent that there are not only great irregularities of form, but that on one side the reef may at times be wholly wanting or deeply submerged.

In many islands there is a ship-entrance through the reef, sometimes six or eight fathoms deep, to the lagoons, where good anchorage may be had; but the larger part have only shallow passages, or none at all. In the Paumotus, out of the twenty-eight visited by the Expedition, not one-half were found to have navigable entrances. In the Carolines, where the islands are large and not so much wooded, entrances are of more common occurrence. About half of the Kingsmill Islands afford a good entrance and safe anchorage. Through these openings in the reefs, there is usually a rapid outward current, especially during the ebbing tide. At Depeyster

Island, it was found to run at the rate of two-and-a-half miles an hour. It was as rapid at Raraka, in the Paumotus, and, as Capt. Wilkes remarks, it was difficult to pull a boat against it into the lagoon.

II. SOUNDINGS ABOUT CORAL ISLANDS.

The water around coral islands deepens as rapidly and in much the same way as off the reefs about high islands. The atoll usually seems to stand as if stilted up in a fathomless sea. The soundings of the Expedition afford some interesting results.

Seven miles east of Clermont Tonnerre, the lead ran out to 1,145 fathoms (6,870 feet), without reaching bottom. Within three-quarters of a mile of the southern point of this island, the lead, at another throw, after running out for a while, brought up an instant at 350 fathoms, and then dropped off again and descended to 600 fathoms without reaching bottom. On the lead, which appeared bruised, a small piece of white coral was found, and another of red; but no evidence of *living* zoophytes. On the east side of the island, three hundred feet from the reef, a bottom of coral sand was found in 90 fathoms; at one hundred and eighty feet, the same kind of bottom in 85 fathoms; at one hundred and thirty feet, a coral bottom in 7 fathoms; and from this it decreased irregularly to the edge of the shore reef.

Off the south-east side of Ahii (another of the Paumotus), about a cable's length from the shore, the lead, after descending 150 fathoms, struck a ledge of rock, and then fell off and finally brought up at a depth of 300 fathoms.

Two miles east of Serle's Island, no bottom was found at 600 fathoms.

A mile and a half south of the larger Disappointment Island, there was no bottom at 550 fathoms.

Near the eastern end of Metia, an island nearly north of Tahiti, no bottom was found with a line of 150 fathoms; and, a mile distant, no bottom was reached at 600 fathoms.

In general, for one to five hundred yards from the margin of the shore reef, the water slowly deepens, and then there is an abrupt descent at an angle of 40 or 50 degrees. The results of earlier voyagers correspond with this statement. At considerable depths, as would appear from the above facts, the sides of the coral structure may be vertical or even may overhang the bottom below.

Beechey, whose observations on soundings are the fullest hitherto published, states many facts of great interest. At Carysfort Island, he found the depth, 60 yards from the surf line, 5 fathoms; 80 yards, 13 fathoms; 120 yards, 18 fathoms; 200 yards, 24 fathoms; and immediately beyond, no bottom with 35 fathoms. At Henderson's Island, soundings continued out 250 yards, where the depth was 25 fathoms, and then terminated abruptly. Off Whitsunday, 500 feet out, there was no bottom at 1,500 feet.

Darwin states other facts bearing upon this subject, of which we may cite the following :—At Heawandoo Pholo (one of the Maldives), Lieutenant Powell found 50 or 60 fathoms close to the edge of the reef. One hundred fathoms from the mouth of the lagoon of Diego Garcia, Captain Moresby found no bottom with 150 fathoms. At Egmont Island, 50 fathoms from the reef, soundings were struck in 150 fathoms. At Cardoo Atoll, only 60 yards from the reef, no bottom was obtained with a line of 200 fathoms. Off Keeling Island, 2,200 yards from the breakers, Captain Fitzroy found no bottom at 1,200 fathoms. Mr. Darwin also states that, at a depth between five and six hundred fathoms, the line was partly cut as if it had rubbed against a projecting ledge of rock; and deduces from the fact "the probable existence of submarine cliffs."

Prof. Agassiz states that the Bahamas and the reefs northeast of Cuba have very great depth close alongside.

There are examples also of less abrupt slopes. North-west of the Hawaiian group, Captain Lisiansky, who commanded the Russian ship *Neva* in a voyage round the world in the years 1860--61, at the island bearing his name, found

shallow water for a distance of six or seven miles; the water deepened to ten or eleven fathoms the first mile, fifteen the second, and at the last throw of the lead there were still but twenty-five-fathoms. Christmas Island affords on its western side another example of gradually deepening waters. Yet these shallow waters terminate finally in a rapid declivity of forty or fifty degrees.

Off the prominent angles of an atoll, soundings generally continue much beyond the distance elsewhere, as was first observed by Beechey. At Washington Island, mostly abrupt in its shores, there is a bank, according to the surveys of the Expedition, extending from the east point to a distance of half a mile; and another on the west extending to a distance of nearly two miles. At Kuria, one of the Kingsmills, soundings continue for three miles from the north extremity, along a bank stretching off from this point to the north northwest. Many other instances might be cited, though they are seldom as remarkable; yet nearly all islands, especially if the points are much prominent, afford similar facts. The Florida reefs, according to Prof. Agassiz, have a gradual slope to seaward instead of the abruptness of the Bahamas. As corals may grow on submerged land of any form, there is no reason why the bottom around should not often deepen gradually. It has been said that the reef to leeward is generally less abrupt than that to windward, but facts thus far obtained are not sufficiently definite or extensive to settle this question. It is probably true, yet the difference, if any, must be small.

III. STRUCTURE OF CORAL ISLANDS.

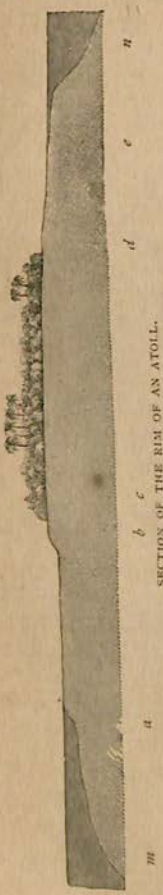
The descriptions of reefs and their islets already given apply with equal force to coral islands. By transferring here the statements respecting the former, we should have a nearly complete account of the latter. The same causes, with scarcely an exception, are at work:—the growing of coral zoophytes, and the action of the waves, of oceanic currents, and of the winds. This resemblance will be rendered more

apparent by a review of their characters. The description will be found to be a simple recapitulation of a former paragraph.

The reef of the coral atoll, as it lies at the surface still uncovered with vegetation, is a platform of coral rock, usually two to four hundred yards wide, and situated so low as to be swept by the waves at high tide. The outer edge, directly exposed to the surf, is generally broken into points and jagged indentations, along which the waters of the resurging wave drive with great force. Though in the midst of the breakers, the edge stands a few inches, and sometimes a foot, above other parts of the platform; the incrusting Nullipores cover it with varied tints, and afford protection from the abrading action of the waves. There are usually three to five fathoms water near the margin; and below, over the bottom, which gradually deepens outward, beds of corals are growing profusely among extensive patches of coral sand and fragments. Generally the barren areas much exceed those flourishing with zoophytes, and not unfrequently the clusters are scattered like tufts of vegetation in a sandy plain. The growing corals extend up the sloping edge of the reef, nearly to low-tide level. For ten to twenty yards from the margin, the reef is usually very cavernous or pierced with holes or sinuous recesses, a hiding-place for crabs and shrimps, or a retreat for the Echini, asterias, sea-anemones and mullusks; and over this portion of the platform, the gigantic Tridacna, sometimes over two feet long and 500 pounds in weight, is often found lying more than half buried in the solid rock, with barely room to gape a little its ponderous shell, and expose to the waters a gorgeously coloured mantle. Further in are occasional pools and basins, alive with all that lives in these strange coral seas.

The reef-rock, when broken, shows commonly its detritus origin. Parts are of compact homogeneous texture, a solid white limestone, without a piece of coral distinguishable, and rarely an imbedded shell. But generally the rock is a breccia or conglomerate, made up of corals cemented into a compact mass, and the fragments of which it consists are sometimes many cubic feet in size.

It is apparent that we are describing a second time an *outer* reef. Without dwelling further upon its characters, we may pass to the features of the reef when raised above the waters and covered with vegetation.



Sections of coral islands and their lagoons have been given by Captain Beechey and Mr. Darwin. We add another, by way of illustration, although little may be presented that is novel after the excellent descriptions of these authors. Sketches of several of these islands, showing the general relation of the rim of land to the reef and the lagoon within, are given in the maps of islands on pages 133, 135. The accompanying sketch represents a section o the rim of land from the sea on one side (the left) to the lagoon on the other. In the view, the part *m a* represents the shallow sea bordering an island, and abruptly deepening one to six hundred feet from the line of breakers. In these shallow waters are the growing corals ; yet, as before stated, a large part is often barren sand or coral rock, especially where the depth is over fifty feet.

From *a* to *b* is the shore platform or reef-rock, nearly at low-tide level, with the margin (*a*) slightly elevated, and usually much incrusted at top with Nullipores. From the platform there is a rise, by a steep beach (*b c*), of six or eight feet, to the wooded part of the coral belt represented between *c* and *d*. From *d* to *e* there is a gently sloping beach bordering the lagoon. Beyond *e*, the waters of the lagoon at first deepen gradually, and then fall off more or less abruptly.

In the Paumotus, the shore platform, the steep beach, and the more gently sloping shore of the lagoon are almost constant characteristics.

The width of the whole rim of land, when the island gives no evidence of late elevation, varies from three hundred yards to one-third of a mile, excepting certain prominent points, more exposed to the united action of winds and waves and often from opposite directions, which occasionally exceed half a mile.

The *shore platform* is from one to three hundred feet in width, and has the general features of a half-submerged outer reef. Its peculiarities arise solely from the accumulations which have changed the reef into an island. Much of it is commonly bare at low tide, although there are places where it is always covered with a few inches or a foot of water; and the elevated edge, the only part exposed, often seems like an embankment preventing the water from running off. The tides, as they rise, cover it with water throughout, and bear over it coral fragments and sand, comminuted shells and other animal remains, to add them to the beach. The heavier seas transport larger fragments; and at the foot of the beach there is often a deposit of blocks of coral, or coral rock, a cubic foot or so in size, which low tide commonly leaves standing in a few inches of water. On moving these masses, which generally rest on their projecting angles and have an open space beneath, the waters at once become alive with fish, shrimps, and crabs, escaping from their disturbed shelter; and beneath, appear various Actiniæ or living flowers, the spiny Echini and sluggish *biche de mar*, while swarms of shells, having a soldier crab for their tenant, walk off with unusual life and stateliness. Moreover, delicate corallines, Ascidiæ and sponges tint, with lively shades of red, green, and pink, the under surface of the block of coral which had formed the roof of the little grotto.

Besides the deep channels cutting into the margin of the reef and giving it a broken outline, there are in some instances long fissures intersecting its surface. On Aratica (Carlshoff) and Ahii (Peacock Island) they extended along from a fourth

half a mile, generally running nearly parallel with the shore, and at top were from a fourth to half an inch wide. These fissures are not essential features of the reef. They are probably a result of a subterranean movement or shaking.

The *beach* consists of coral pebbles or sand, with some worn shells, and occasionally the exuviæ of crabs and bones of fishes. Owing to its whiteness, and the contrast it affords to the massy verdure above, it is a remarkable feature in the distant view of these islands, and often seemed like an artificial wall or embankment running parallel with the shores. On Clermont Tonnerre, the first of these islands visited by us, the natives seen from shipboard, standing spear in hand along the top of the beach, were believed by some to be keeping patrol on the ramparts of a kind of fortification. This deception arose from the dazzling whiteness of the coral sand, in consequence of which, the slope of the beach was not distinguished in the distant view.

The *emerged land* beyond the beach, in its earliest stage, when barely raised above the tides, appears like a vast field of ruins. Angular masses of coral rock, varying in dimensions from one to a hundred cubic feet, lie piled together in the utmost confusion; and they are so blackened by exposure, or from incrusting lichens, as to resemble the clinkers of Mauna Loa; moreover, they ring like metal under the hammer. Such regions may be traversed by leaping from block to block, with the risk of falling into the many recesses among the huge masses. On breaking an edge from the black masses, the usual white colour of coral is at once apparent. Some of the blocks, measuring five or six feet in each of their dimensions, were portions of single individual corals; while others had the usual conglomerate character of the reef-rock, or, in other words, were fragments torn by the waves from the reef-rock.

In the next stage, coral sand has found lodgment among the blocks; and although so scantily supplied as hardly to be detected without close attention, some seeds have taken root, and vines, purslane, and a few shrubs have begun to grow, relieving the scene, by their green leaves, of much of its desolate aspect.

Both of these stages are illustrated on the greater part of coral islands.

In the last stage, the island stands six to ten feet out of water. The surface consists of coral sand, more or less discoloured by vegetable or animal decomposition. Scattered among the trees stand, still uncovered, many of the larger blocks of coral, with their usual rough angular features and blackened surface. There is but little depth of coral soil, although the land may appear buried in the richest foliage. In fact, the soil is scarcely anything but coral sand. It is seldom discoloured beyond four or five inches, and but little of it to this extent; there is no proper vegetable mould, but only a mixture of darker particles with the white grains of coral sand. It is often rather a coral gravel, and below a foot or



1 2

BLOCKS OF CORAL ROCK ON THE SHORE PLATFORM.

two it is usually cemented together into a more or less compact coral sand-rock.

One singular feature of the shore platform, occasionally observed, remains to be mentioned. Huge masses of reef rock are sometimes found upon it, some of which lie loose upon the reef, while others are firmly imbedded in it below, and so cemented to it as to appear to be actually a part of the platform rock. Sketches of two of these masses are given above.

Figure 1 represents a mass on the island of Waterland (one of the Paumotus), six feet high and about five in diameter; it was solid with the reef-rock below, as though a part of it; and, about two feet above its base it had been so nearly worn off by the waters as to have become irregularly top-

shaped. Another mass, similarly attached to the reef at base, observed on Kawehe (Vincennes Island), was six feet high above low-water level, and seven feet in its longest diameter. Below, it had been worn like the one just described, though to a less extent. Another similar mass was eight feet high. Figure 2 represents a block six feet high and ten feet in its longest diameter, seen on Waterland; it was unattached below, and lay with one end raised on a smaller block. On Aratica (Carlshoff), others were observed. One loose mass like the last was eight feet high and fifteen feet in diameter, and contained at least a *thousand cubic feet.* Raraka also afforded examples of these attached and unattached blocks, some standing with their tops six feet above high-water mark.

These masses are similar in character to many met with among the fields of blocks just described, and differ only in having been left on the platform instead of transported over it. Some of them are near the margin of the reef, while others are quite at its inner limit. The second mass alluded to above, on Kawehe, was a solid conglomerate, consisting of large fragments of Astræas and Madrepores, and contained some imbedded shells, among which an Ostræa and a Cypræa were noticed. This is their usual character. The other two were parts of large individual corals (Porites); but there was evidence in the direction of the cells that they did not stand as they grew; on the contrary, they had been upthrown, and were afterward cemented with the material of the rock beneath them, probably at the time this rock itself was consolidated. Below some of the loose masses the platform was at times six inches higher than on either side of the mass, owing to the protection from wear given to the surface beneath it. These blocks are always extremely rough and uneven, like those of the emerging land beyond; and the angular features are partly owing, in both cases, to solution from rains and from the dashes of sea-water to which, with every tide, they are exposed.

It should be distinctly understood that these masses here described were found isolated, and only at considerable intervals. In no instance were they observed clustered. The loose

blocks and those cemented below had the same general character, and must have been placed where they were by the same cause, though it may have been at different periods.

Such blocks are of course not confined to coral island reefs, but belong to barrier reefs generally.

Jukes says, "I once landed close to the edge of the Australian barrier on the south side of the Blackwood channel, in south latitude 11° 44′ on a *continuous mass of Porites which was at least twenty feet across*, and it seemed to pass downwards into the mass of the reef below water without any disconnection. It was worn into pinnacles above, so that two or three of us could stand in the different hollows without seeing each other; and it was one of a line of such masses that attracted our attention for a distance of three miles."

The shore of the lagoon is generally low and gently inclined, yet in the larger islands, in which the waters of the lagoon are much disturbed by the winds, there is usually a beach resembling that on the seaward side, though of less extent. A platform of reef-rock at the same elevation as the shore platform sometimes extends out into the lagoon; but it is more common to find it a little submerged, and covered for the most part with growing corals; and in either case, the bank terminates outward in an abrupt descent, of a few yards or fathoms, to a lower area of growing corals, or a bottom of sand. Still more commonly, we meet with a sandy bottom gradually deepening from the shores without growing coral. These three varieties of condition are generally found in the same lagoon, characterizing its different parts. The lower area of growing corals slopes outward, and ceases where the depth is 10 to 12 fathoms, or sooner; from this there is another descent to the depth which prevails over the lagoon. On some small lagoons the shore is a thick plastic mud, either white or brownish, and forms a low flat which is very gently sloping. On Henuake, these mud deposits are quite extensive, and of a white colour. At Enderbury's Island, another having a shallow lagoon, the mud was so deep and thick that there was some difficulty in reaching the waters of the lagoon; the foot sank in eight or ten inches,

and was not extricated without some difficulty. It looked like a dirty brownish clay. This mud is nothing but comminuted coral, so fine as to be almost impalpable.

The *lagoons* of the smaller islands are usually very shallow; and in some, merely a dry bed remains, indicating the former existence of water. Instances of the latter kind are met with only in islands less than three miles in diameter; and those with shallow lagoons are seldom much larger. These shallow waters, when direct communication with the sea is cut off, become, in some instances, very salt by evaporation, and contain no growing coral, with few signs of life of any kind; and in other cases, they are made too fresh for marine life through the rains. At Enderbury's Island the water was not only extremely saline, but the shores of the lagoon were in some places incrusted with salt. But when there is an open channel, or the tides gain access over a bare reef, corals continue to grow; and a considerable portion of the lagoon may be obstructed by them. At Henuake, the sea is shut out except at high water, and there were consequently but few species of corals, and those of small size. At Ahii (Peacock's Island), there was a small entrance to the lagoon, and though comparatively shallow, corals were growing over a large part of it.

In the larger islands, the lagoons contain but small reefs compared with their whole extent; the greater part is an open sea, with deep waters and a sandy or muddy bottom. There are instances, as at the sourthern Maldives, of a depth of fifty and sixty fathoms. From twenty to thirty-five fathoms is the usual depth in the Paumotus. This was the result of Captain Beechey's investigations; and those of the Expedition, though few, correspond. It is however probable that deeper soundings would be found in the large island of Nairsa (Dean's). In Gilbert's Group, south-east of the Carolines, the depth, where examined by the Expedition, varied from two to thirty-five fathoms. Mr. Darwin found the latter depth at Keeling's Island. Chamisso found twenty-five to thirty-five fathoms at the Marshall Islands.

The bottom of these large lagoons is very nearly uniform, varying but little except from the occasional abrupt shallowings produced by growing patches of reef. Soundings bring up sand, pebbles, shells, and coral mud; and the last mentioned material appears to be quite common, even in lagoons of considerable size. It has the same character as above described. The bluish clay-like mud of the harbour of Tongatabu may be classed with these deposits. Darwin describes this mud as occurring at the Maldives, and at Keeling's Island (op. cit. p. 26); Kotzebue mentions it as common at the Marshall atolls, and Lieutenant Nelson observed it at the Bermudas. It appears, therefore, that the finer coral material of the shores prevails throughout the depths of the lagoon. The growing reefs within the lagoons are in the condition of the *inner* reefs about high islands. The corals grow but little disturbed by the waves, and the reef-rock often contains them in the position of growth. At Taputeouea (Kingsmill's or Gilbert's Group), reefs very similar to those of the Feejees occur; they contain similar large Astræas ten to twelve feet in diameter, which once were growing where they stand, but are now a part of the solid lifeless rock.

Beach formations of coral sand-rock are common on the coral islands, and they present the same features in every respect as those described. They were observed among the Paumotus, on Raraka, Honden, Kawehe, and other islands. The stratified character is always distinct, and the layers slope toward the water at the usual small angle, amounting to 5—7 degrees bordering the lagoon, and 6—8 degrees on the seashore side of the land. Agassiz gives the same angle for the seaward slope of similar deposits at Key West. The rock is largely a fine oölite. They often occupy a breadth of thirty to fifty yards, appearing like a series of outcrops; yet they are frequently covered by the sands of the steep part of the beach. It is probable that they generally underlie the loose surface material of the land. The rock is a fine or coarse sand-rock, or an oölite, or a coral pudding-stone, and consists of beach materials. Occasionally it is quite compact, and resembles common lime-

stone, excepting in its whiter colour; but generally its sand origin is very apparent. On the northern atolls of the Maldives the beach sand-rock is said to be quarried out in square blocks and used for building.

In borings by Lieutenant Johnson, of the Wilkes Exploring Expedition, on Aratica or Carlshoff's Island, in the Paumotus, ten or eleven feet were passed through easily, and then there was a sudden transition from this softer rock (probably the beach sand-rock) to the solid reef-rock.

The *drift sand-rock* was not met with by the author on any of the coral islands visited. The time for exploration on these islands allowed by the Expedition was too short for thorough work. It has been stated that the more exposed points toward the trades, especially the north-eastern and south-western, are commonly a little higher than other parts; and it is altogether probable that some of the sand-heaps there formed will prove on examination to afford examples of this variety of coral-rock. Such situations are exactly identical with those on Oahu, where they occur on so remarkable a scale. Mr. R. H Schomburgh, in an article in the Journal of the Royal Geographical Society, vol. ii. p. 152, states that on the island of Anegada, in the West Indies, the drift-banks on the windward shores are forty feet in height, and that behind the first range there is a second, and even a third.

Although in these descriptions of atolls, some points have been dwelt upon more at length than in the description of barrier reefs, still it will be observed that the former have no essential peculiarities of structure apart from such as necessarily arise from the absence of high rocky lands. The incircling atoll reef corresponds with the outer reefs that inclose high islands; and the green islands and the beach formations, in the two cases, originate in the same manner.

The lagoons, moreover, are similar in character and position to the inner channels within barrier reefs; they receive coral material only from the action of degrading agents, because no other source of detritus but the reefs is at hand. The

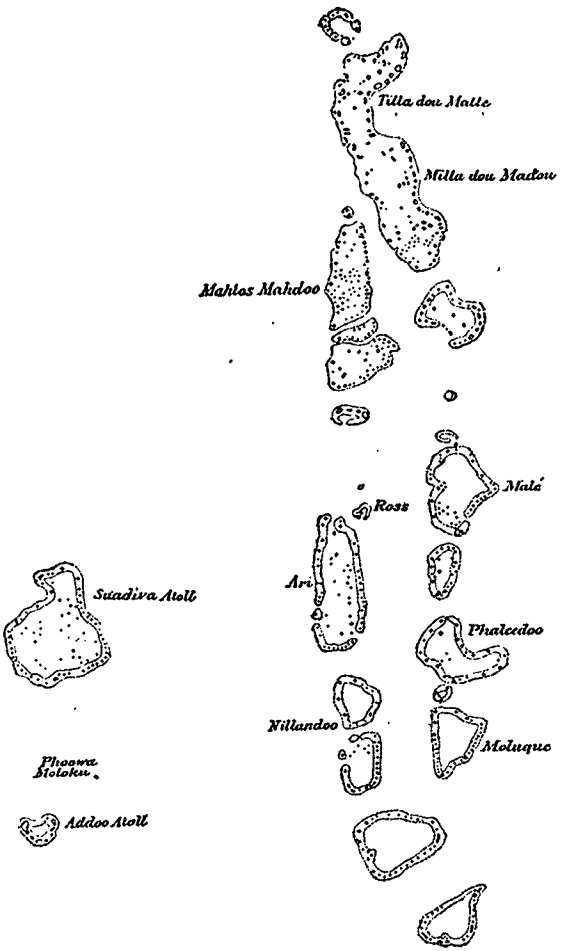
accumulations going on within them are, therefore, wholly of coral. The reefs within the lagoons correspond very exactly in mode of growth and other characters to the *inner* reefs under the lee of a barrier.

IV. NOTICES OF SOME CORAL ISLANDS.

The preceding descriptions represent the general character of atolls, but are more especially drawn from the Paumotus. There are some peculiarities in other seas to which we may briefly allude.

Among the scattered coral islands north of the Samoan Group, the shore platform is seldom as extensive as at the Paumotus. It rarely exceeds fifty yards in width, and is cut up by passages often reaching almost to the beach. In some places the platform is broken into islets. Enderbury's Island is one of the number to which this description applies. The beach is eleven or twelve feet high. For the first eight feet it slopes very regularly at an angle of thirty to thirty-five degrees, and consists of sand, coarse pebbles, or rounded stones of coral, with some shells; and there is the usual beach conglomerate near the water's edge. After this first slope, it is horizontal for eighty to two hundred feet, and then there is a gradual rise of three to four feet. Over this portion there are large slabs of the beach conglomerate, along with masses from the reef-rock, and some thick plates of a huge foliaceous Madrepora; and these slabs, many of which are six feet square, lie inclining quite regularly against one another, as if they had been taken up and laid there by hand. They incline in the same direction with the slope of the beach. The large Madrepora alluded to has the mode of growth of the *Madrepora palmata;* and probably the entire zoöphyte extended over an area twelve or fifteen feet in diameter. The fragments are three to four inches thick, and thirty square feet in surface.

As a key to the explanation of the peculiarities here observed, it may be remarked that the tides in the Paumotus are two to three feet, and about Enderbury's Island five to six feet, in height.



MALDIVE ARCHIPELAGO (ONE INCH TO 60 MILES).

Maldive Archipelago.—The Maldives have been often appealed to in illustration of coral structures. They are particularly described by Mr. Darwin from information communicated to him by Captain Moresby, and from the charts of this officer and Lieutenant Powell. A paper on the Northern Maldives, by Captain Moresby, is contained in the Journal of



MAHLOS MAHDOO ATOLL, WITH HORSBURGH ATOLL (1/10 OF AN INCH TO A MILE)

the Royal Geographical Society, vol. v. p. 398; and another on this group by J. J. Horsburgh, and W. F. W. Owen, in the same journal, vol. ii. pp. 72 and 81. As stated by Mr. Darwin, the archipelago has a length of 470 miles, with an average breadth of fifty miles; and it consists for the most of its length of two parallel lines of atolls. The large atoll at the north end has a length of eighty-eight miles, while Suadiva, one of the southern-

most, is forty-four miles long from north to south, and thirty-four miles across.

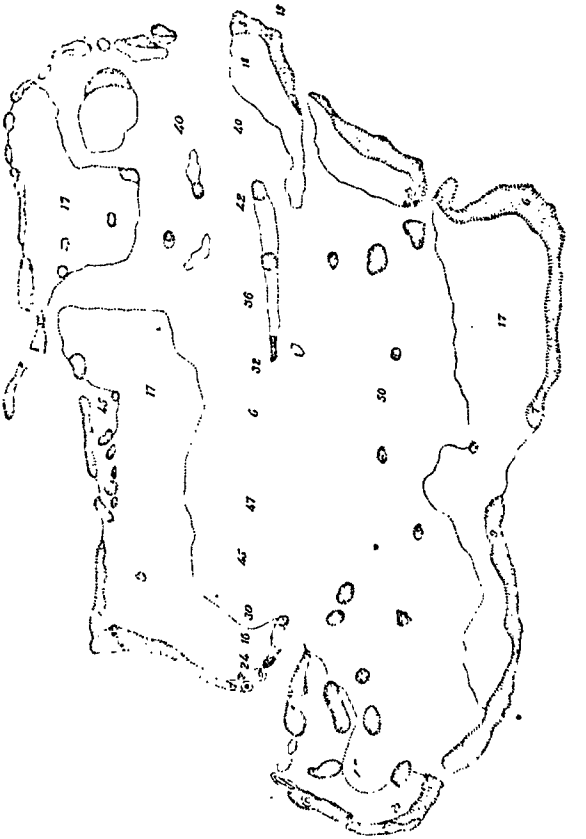
The point of special interest in their structure is the occurrence of atolls or annular reefs within the larger atolls. The islets of the lagoon and those of the incircling reef are in many instances annular reefs, each with its own little lake. Gems within gems are here clustered together.

This feature is well exhibited in the Mahlos Mahdoo atoll, an enlarged map of which, from Darwin's work, is inserted on the preceding page. The atoll consists of three main atoll-shaped portions; but in each of these, the border is made up in part of atolls. Many of the subordinate atolls of the border are "three, and some even five miles in diameter, while those within the lagoon are usually smaller, few being more than two miles across, and the greater number less than one. The depth of the little lagoons within these small annular reefs is generally from five to seven fathoms, but occasionally more; and in Ari atoll, many of the central ones are twelve, and some even more than twelve fathoms deep. These subordinate atolls rise abruptly from the platform or bank on which they stand, with their outer margin bordered by living corals." "The small atolls of the border, even where most perfect and standing farthest apart, generally have their longest axis directed in the line which the reef would have held if the atoll had been bounded by an ordinary wall." (Darwin on Coral Reefs, pp. 33, 34.)

The Maldives are among the largest atoll-reefs known; and they are intersected by many large open channels; and Mr. Darwin observes, that the interior atolls occur only near these channels, where the sea has free access. We may view each large island in the archipelago as a sub-archipelago of itself. Although thus singular in their features, they illustrate no new principles with regard to reef-formations.

Mr. Darwin thus remarks (op. cit. pp. 33, 34),—"I can in fact point out no essential difference between these little ring-formed reefs (which, however, are larger, and contain deeper lagoons than many true atolls that stand in the open sea), and the most perfectly characterized atolls, excepting

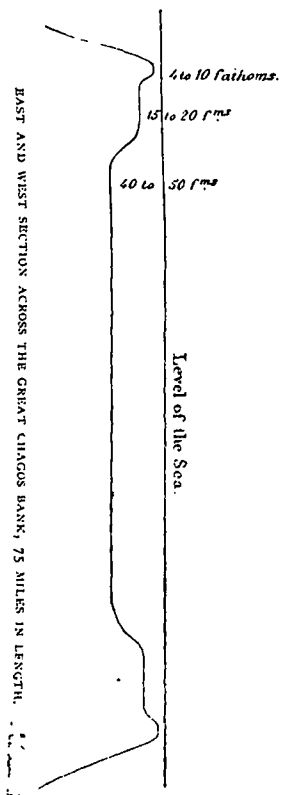
that the ring-formed reefs are based on a shallow foundation instead of on the floor of the open sea, and that instead of being scattered irregularly, they are grouped closely together."—"It



GREAT CHAGOS BANK.

appears from the charts on a large scale, that the ring-like structure is contingent on the marginal channels or breaches being wide, and, consequently, on the whole interior of the

atoll being freely exposed to the waters of the open sea. When the channels are narrow, or few in number, although the lagoon be of great size and depth (as in Suadiva), there are no ring-formed reefs; where the channels are somewhat broader, the marginal portions of reef, and especially those close to the larger channels, are ring-formed, but the central ones are not so: where they are broadest, almost every reef throughout the atoll is more or less perfectly ring-formed. Although their presence is thus contingent on the openness of the marginal channels, the theory of their formation, as we shall hereafter see, is included in that of the parent atolls, of which they form the separate portions."



EAST AND WEST SECTION ACROSS THE GREAT CHAGOS BANK, 75 MILES IN LENGTH.

The Great Chagos Bank. — This bank lies about ten degrees south of the Maldives, and is ninety miles long and seventy in its greatest breadth. It is a part of the Chagos Group, in which there are some true atolls, some bare atoll-reefs, and others, like the Great Chagos Bank, that are quite submerged, or nearly so. Its rim is mostly from four to ten fathoms under water.

Mr. Darwin confirms the opinion of Captain Moresby, that this bank has the character of a lagoon reef, resembling one of the Maldives; and he states, on the evidence of extensive soundings, that, if raised to the surface, it would actually become a coral island, with a lagoon

forty fathoms deep. He says that, in the words of Captain Moresby, it is in truth "nothing more than a half-drowned atoll."

The form of the bank, its margin of shoals, and a line of soundings across it, giving the depth of the central or lagoon portion, are shown in the map on p. 155, from Darwin, and for which, as well as for other information about the bank, he gives credit to Captain Moresby. The cross section is still further illustrated in the cut on p. 156. The whole length of the section (or width of the bank in the line of the soundings) is seventy-six miles. From the outer rim of the submerged atoll there is a drop off to a deeper level, which is mostly fifteen to eighteen fathoms below the surface; and then to the bottom of what was once the lagoon, now for the most part forty to fifty fathoms under water, though having its shoals that are five to ten fathoms submerged. All points in the map that are shaded have a depth of less than ten fathoms; the only emerged parts are three or four spots on the western margin, as indicated on the map. The bottom over the interior is muddy; on the flat bordering it, fifteen to twenty fathoms deep, there is coral sand with "a very little live coral; the outer rim is coral rock with scarcely any live coral;" while the shoals or knolls of the interior are "covered with luxuriantly-growing corals." Darwin states also that the rim is steep on both sides, and outward slopes abruptly to unfathomable depths; at a distance of less than half a mile from one part no bottom was found with 190 fathoms; and off another point, at a somewhat greater distance, there was none with 210 fathoms.

Metia and other elevated Coral Islands.—Metia, or Aurora Island, is one of the western Paumotus. It is a small island about four miles by two and a half in width, and two hundred and fifty feet in height; and it consists throughout of coral limestone. Approached from the north-east, its high vertical cliffs looked as if basaltic, resembling somewhat the Palisades on the Hudson. This appearance of a vertical structure was afterwards traced to vertical furrowings by the waters dripping down its front, and the consequent formation of stalagmitic incrustations. Deep caverns were also seen.

The cliff, though vertical in some parts, is roughly sloping in others, and on the west side the surface of the island gradually declines to the sea.

The rock is a white and solid limestone, seldom presenting any traces of its coral origin. In some few layers there were disseminated corals, looking like imbedded fossils, along with beautiful casts of shells; but for the most part it was as compact as any ancient limestone, and as uniform in texture. Occasionally there were disseminated spots of crystallized calcite.

The caverns contain coarse stalactites, some of which are six feet in diameter; and interesting specimens were obtained



METIA, OR AURORA ISLAND.

containing recent land shells that had been inclosed by a calcareous film while hibernating.

It is probable that more extensive caverns would have been found had there been more than a few hours for the examination of the island. The Rev. Mr. Williams, in his work on Missionary Enterprises in the Pacific, gives very interesting descriptions of caverns in the *elevated* coral rock of Atiu, one of the Hervey Group. In one, he wandered two hours, without finding a termination to its windings, passing through chambers with "fretwork ceilings of stalagmite and stalactite columns, which, 'mid the darkness, sparkled brilliantly with the reflected torch-light." This author remarks, "that while the madrepores, the brain and every other species of coral are full of little cells, these islands (including those resembling Atiu),

appear to be *solid masses of compact limestone, in which nothing like a cell can be detected.*"

Beechey, in his description of Henderson Island, another of this character, speaks of the rock as *compact, and having the fracture of a secondary limestone.*

The surface of the island is singularly rough, owing to erosion by rains. The paths that cross it wind through narrow passages among ragged needles and ridges of rock as high as the head, the peaks and narrow defiles forming a miniature model of the grandest Alpine scenery. There is but little soil, yet the island is covered with trees and shrubbery.

The shores of the first elevation of the island must have been worn away to a large extent by the sea; and the cliff and some isolated pinnacles of coral rock still standing on the coast are evidence of the degradation. But at present there is a wide shore-platform of coral reef, two hundred or two hundred and fifty feet wide, resembling that of the low coral islands, and having growing coral, as usual, about its margin and in the shallow depths beyond.

In the face of the cliff there are two horizontal lines, along which cavities or caverns are most frequent, which consequently give an appearance of stratification to the rock, dividing it into three nearly equal layers.

We might continue this account of coral reefs and islands by particular descriptions of others in the Pacific. But the similarity among them is so great, and their peculiarities are already so fully detailed, that this would amount only to a succession of repetitions. The characters of a few, briefly stated, will suffice in this place :—

Jarvis's Island.—(Fig. 3, page 135.) Lat. 0° 22′ S.; Long. 159° 58′ W. Two miles long by one mile wide, and trending east and west. No lagoon, but a basin-like depression over its interior, which at bottom is seven or eight feet above the sea, and in which the lagoon once existed; old beach lines are distinguishable in it. Its surface is a low sandy flat, eighteen or twenty feet high, without trees, and partly covered with

small shrubs. A high sloping beach continuous around. Has a shore platform about 300 feet wide.

Birnie's.—Lat. 3° 35′ S.; Long. 171° 30′ W. Four-fifths of a mile by one-third, trending north-west. No lagoon. A sandy flat about ten feet high, except near the north-north-east extremity, where it is about twelve feet. To the south-south-west the submerged reef extends out nearly a mile, over which the sea breaks. In passing it, distinguished no vegetation except the low purslane and some trailing plants.

Swain's.—(Fig. 4, page 135.) Lat. 11° 10′ S.; Long. 170° 52′ W. 1¼ miles by ⅔; shape nearly rectangular; trends east and west. No lagoon, but the centre a little lower than the sides. Surface covered with shrubbery and large trees, among the latter many cocoa-nuts; the centre more sparsely wooded. Height fifteen to eighteen feet, excepting on the middle of the western side, where the surface is covered with loose fragments of coral of small size; there appears to have been a former entrance to the lagoon at this place. Shore reef, or platform, one hundred yards in average width, and one hundred and fifty yards at the place where we landed. Beach high, ten to twelve feet. At lower part of beach, for a height of two to three feet, the coral reef-rock was exposed, indicating an elevation of the island. For three or four feet above this, layers of the beach sand-rock were often in view, consisting of coral pebbles firmly cemented, and having the usual dip of seven or eight degrees seaward; in many places it was concealed by the beach sands and pebbles. There was no growing coral on the platform, excepting Nullipores. The outer margin of this platform was very uneven, and much intersected by channels, though less so than at Enderbury's Island. Great numbers of Birgi (large Crustacea) were burrowing over the island, some of which were six inches in breadth.

Otuhu, Paumotu Archipelago.—14° 5′ S.; 141° 30′ W. 1½ miles by ⅝, trending north and south. No lagoon. Wooded.

Margaret, Paumotu Archipelago.—20° 42′ S.; 143° 4′ W. Diameter one mile, nearly circular. A small shallow lagoon

with no entrance. North-east side alone wooded, and in two patches.

Teku or Four Crowns, Paumotu Archipelago.—20° 28′ S. 143° 18′ W. Diameter 1½ miles, nearly circular. A small lagoon with no entrance. South-western reef bare; five patches of forest on the other part.

Washington Island.—Lat. 4° 41′ N. Long. 160° 15′ W. 3 miles by 1¼, trending east and west. It is a dense cocoa-nut grove with luxuriant shrubbery. No lagoon. The shore platform is rather narrow. A point of submerged reef, one-and-a-half miles long, stretches out from the southwest end. Did not land on account of bad weather.

Enderbury's.— 3° 8′ S. 171° 15′ W. 2¾ miles by 1 mile nearly, trending N. N. W. and S. S. E.; form trapezoidal or nearly rectangular. Little vegetation on any part, and but few trees. The lagoon very shallow, and containing no growing coral; its shores of coral mud, allowing the foot to sink in eight or ten inches, and covered in places with saline incrustations. Shore platform one hundred feet or less in width, and surface inclined outward at a very small angle; covered with three or four feet of water at high tide, and with few corals or shells; beyond this, falls off four to six feet, and then the bottom inclines for one hundred yards or more. The beach very high and regular; rises eight feet at an inclination of thirty to thirty-five degrees; then horizontal for eighty to two hundred, after which another rise of three or four feet. It consists of pebbles and fine sand, but above of slabs and blocks of coral rock and of the beach sand rock, those of the latter nearly rectangular and flat. This beach sand-rock occurs in layers from ten to twenty inches thick along the shore, and is inclined from five to seven degrees seaward. Some portions are very compact, and ring under the hammer, while others inclose fragments of different sizes to a foot or more in diameter. Large trunks of transported trees lay upon the island, one of which was forty feet long and four in diameter. The shore platform was much intersected by channels.

Captain Hudson obtained soundings half a mile off in two hundred fathoms; the lead struck upon a sandy bottom, but was indented by coral.

Honden or *Henuake*, Paumotu Archipelago.—Size $3\frac{1}{2}$ miles by 2 miles. Oblong, five-sided; trending west-north-west. A small shallow lagoon, communicating with the sea only at high tide, on the west side. There are two other entrances which are seldom if ever covered with water, and appeared merely as dry beds of coral rock. Height of the island twelve feet: lowest on the south side. Belt of verdure complete, and consisting of large forest trees, with the Pandanus and other species, but no cocoa-nuts; its breadth half a mile, and in some parts three-fourths. Among the trees large masses of coral rock often exposed to view, and the surface in many parts very rough. It seemed surprising at all these islands that there should be so luxuriant a growth of trees and shrubbery over so rocky a surface. Shores of the lagoon nearly flat. On one side there was a large area of extremely fine coral sand and mud, which extended a long distance into the lagoon. Elsewhere about the centre of the island, the reef-rock was bare, and contained numerous shells of Tridacnæ. A few small Madrepores still growing in the lagoon. Beach on the sea-shore side eight feet high. In lower part of beach, several layers of white limestone (the beach sand-rock), formed of coral fragments or sand, shells, &c., much of which was very compact. The layers inclined toward the sea at an angle of about six degrees. Shore platform as elsewhere in this archipelago.

The facts above stated are evidence of a slight elevation, probably not exceeding three feet.

Taiara, or *King's*, Paumotu Archipelago.—15° 42′ S.; 144° 46′ W. $2\frac{3}{8}$ miles by $1\frac{3}{4}$, trending north-west. Has a small lagoon with no entrance. Reef almost continuously wooded around, somewhat broken into patches.

Sydney Island.—Lat. 4° 20 S. Long. 171° 15′ W. Trends north-east and south-west. Well wooded nearly all round; but on leeward side the forest in patches, with breaks of bare coral.

Lagoon narrow, without entrance. Width of island from sea to lagoon, one hundred to four hundred yards: width greatest at south end. Beach ten feet high. The soil of the island consisted of coral fragments and sand. Shore platform fifty to eighty feet wide; five or six feet of water over it at high tide. Cut up very irregularly by channels three to eight or ten feet wide. Observed small corals growing on the bottom outside of the platform. Shores of lagoon shallow for fifty yards, and consisting of coral sand. Beyond this a slope covered with growing corals; the corals rather tender species of Madrepores. In the interior of the lagoon many knolls and large patches of coral.

Duke of York's.—8° 38′ S., 172° 27′ W. Form irregularly oblong, trending north-west. Length, $3\frac{3}{4}$ miles; breadth, 2 miles. Circuit, $9\frac{1}{2}$ miles, and about one-half wooded in patches. South-west reef mostly bare. A lagoon, but without entrance except for canoes at high tide, on leeward side. Island ten feet high. Shore platform narrow, and intersected by channels. Shores lined by reef-rock, two or three feet out of water, indicating an elevation of the island. This reef-rock consists of various corals firmly cemented. Within the lagoon, knolls of coral, but none near the shore on the leeward side.

Fakaafo or *Bowditch's.*—9° 20′ S., 171° 5′ W. $6\frac{3}{4}$ miles by 4. Shape nearly triangular. Circuit seventeen miles, about six of which are wooded in several patches, separated by long bare intervals. A large lagoon, but no ship entrance. Height of island, fifteen feet. Width to the lagoon, one hundred to two hundred yards. Soil of the island coral sand, speckled black with results of vegetable decomposition. Shore platform narrow. At outer edge a depth of three fathoms, and from thence gradually deepens, and abounds in corals for fifty yards, when it deepens abruptly. Coral reef-rock elevated three or four feet, indicating an elevation of the island. Lagoon shallow, with some growing coral, but none near the shore. Some corals growing on the platform, near its margin, mostly small Madrepores, Astræas, Nullipores. Fragments of pumice were found among the natives, which had floated to the island

Ahii, or *Peacock's Island*, Paumotu Archipelago.—14° 30″ S., 146° 20″ W. 13 miles by 6, trending N. E. by E. Shape irregularly oblong. A large lagoon, having an entrance for small vessels on the west. Reef wooded throughout nearly its whole circuit. Lagoon shallow, and much obstructed by growing coral, the latter giving the water over it a clear light green colour. Platform, or outer coral shelf of the island, about two hundred and fifty feet wide; under water except at the lowest tides. Margin highest, and covered with Nullipore incrustations, which give it a variety of delicate shades of colour, mostly reddish, of peach-blossom red, rose, scarlet. For thirty to fifty feet from the margin, very cavernous, and containing many Tridacnæ, lying half imbedded, with the variously tinted mantle expanded when the surface is covered with water. Rock of the platform either a compact white limestone or a solid conglomerate; dead over its surface, excepting a few Madrepore tufts or Astræas near the margin in pools. In this shelf there were long fissures, extending nearly parallel with the shore, a quarter to half an inch wide at top, and continuing sometimes a fourth of a mile or more. These fissures were commonly filled with coral sand. The higher parts of the island either consisted of loose blocks of coral or were covered with some soil; the soil mostly of comminuted coral and shells, with dark particles from vegetable decomposition intermingled. On the bottom, exterior to the shore platform, observed the same corals growing as occurred in fragments upon the island; but the larger part of the bottom was without coral, or consisted only of sand.

Raraka, Paumotu Archipelago.—16° 10′ S., 145° W. 14 miles by 8, trending east and west. Shape somewhat triangular. North side nearly continuously wooded; south angle and south-west reef bare. A large lagoon, with an entrance for small vessels on the north side. A rapid current flows from the entrance, which it was difficult for a boat to pull against. Shore platform, as usual, about a hundred yards wide, with the edge rather higher than the surface back; the platform mostly bare of water at low tide. Several large masses of coral and

coral rock, one to four hundred cubic feet, on the platform and upon the higher parts of the island, some of which stood five and six feet above high-water mark; they were cemented to the reef-rock below, and appeared like projecting parts of the reef. Layers of beach sand-rock on the lagoon shores, as well as on the seaward side, inclined at an angle of six or seven degrees; characters as already described. Growing coral in the entrance to the lagoon, within two feet of the surface, mostly a species of Millepora (*M. squarrosa*). Interior of the lagoon not examined, no time being allowed for it by the Expedition. The water looked as blue as the ocean, and was much roughened by the winds.

Kawehe, or *Vincennes Island*, Paumotu Archipelago, 15° 30′ S., 145° 10′ W. 13 miles by 9, trending north-north-west. Shape irregularly oval. Having a large lagoon, and mostly wooded around, least so to leeward. Between the wooded islets (as on Raraka and elsewhere), surface consisted of angular masses of coral rock (among which the Porites prevail), strewed in great numbers together; and in some parts bearing a few vines and purslane among the blocks, though scarcely any appearance of soil, or even of coral sand. In other parts, not as high, no vegetation, and surface still wet by high tide. A few large masses of coral on the shore platform, either lying loose or firmly attached below, as already described; some of them were six feet cube, and one was raised seven feet above high-water mark. Shore platform about a hundred yards wide, rather highest at the edge, and much of its surface two to three feet under water at low tide. As elsewhere, this platform is nothing but a compact coral conglomerate or limestone, having no growing coral over it, except in some shallow pools near its outer margin, where also there are numerous holes in which crabs are concealed, with small fish and other animals of the shores. On the lagoon shore, layers of beach sand-rock, six or seven in number, dipping at an angle of seven degrees toward the lagoon, and outcropping one above the other. Similar layers on the sea-shore side.

Manhii, Wilson's or *Waterlandt*, Paumotu Archipelago, 14°

25′ S., 146° W. 15 miles by 6, trending E. N. E. A large lagoon with a deep entrance on the west side. Shape oblong triangular.

Shore platform as usual; mostly under water at low tide. Large masses of coral here and there, standing on this reef, either cemented to it or loose. One top-shaped mass is figured on p. 146. High water did not reach the part of it which was most worn; and this was evidently owing to the fact that the action of the swell or waves is greatest above the actual level of the tide at the time. The reef-rock is either a compact limestone, showing no traces of its composite origin, or a conglomerate. Beach, regular as usual, six to ten feet high, consisting of coral sand, and fragments of worn shells, with occasional exuviæ of crabs, remains of Echini, fish, &c. The entrance to the lagoon is deep and narrow, with vertical sides.

Aratica or *Carlshoff*, Paumotu Archipelago, 15° 30′ S., 145° 30′ W. 17 miles by 10, trending N. E. Large lagoon with a good entrance for vessels. The reef fronting south bare for nine miles; on north-west side, mostly very low, with only here and there a clump of trees; occasionally a line of wooded land for a quarter of a mile on the east side; more continuously wooded on the north. The bare parts mostly covered with blocks of coral, one to thirty cubic feet and larger, tumbled together as on the preceding. Some blocks of coral on the shore platform very large; one eight feet high and fifteen in diameter, containing at least 1,000 cubic feet.

Nairsa or *Dean's*, Paumotu Archipelago, 15° S., 148° W. 44 miles by 17, trending W. N. W. Northern shore mostly wooded; southern with only an occasional islet, connected by long lines of bare reef. In these intervals, the reef stood eight feet or so out of water, according to estimate from ship-board, and was worn into a range of columns, or excavated with caverns, so as to look very much broken, though quite regularly even in the level of the top line.

We might continue these descriptions; but the above, with the details before given, will convey a general idea of the whole.

Florida Reefs and Keys.—This region of coral formations has been described by Prof. M. Tuomey (*American Journal of Science*, vol. xi., 1851), Professor Agassiz (Coast Survey Reports for 1851 and 1866, and Bull. Mus. Comp. Zoöl., i., 363), and Captain E. B. Hunt (*Am. J. Sci.*, xxxv., 1863). A few paragraphs from the papers of the first two of these observers are here cited. The map at the close of the volume illustrating this Florida reef-region is from the Report on Deep-Sea Corals of L. F. de Pourtales, published in the Illustrated Catalogue of the Museum of Comparative Zoölogy in 1871. First, from Professor Tuomey :—

"Key West is about six miles in length and two miles wide, the highest point being fifteen or twenty feet above mean tide. The deepest wells are about fifteen feet in depth ; the water in them, which is slightly brackish, ebbs and flows with the tide." "The rock perforated in these wells, like that everywhere else exposed, is sufficiently soft to yield readily to the axe, with the exception of a thin crust of a few inches on the surface, which is quite hard, especially where it is exposed alternately to the action of the tides and atmosphere. This indurated crust may be seen on the road between the town and the barracks, and around the salt works. Below this crust the rock is quite soft, and in some other respects resembles the Alabama white limestone; but the most striking difference next to that of organic remains, consists in the distinctly oolitic structure of the Florida limestone. This structure is seen where one would be led to expect it, in the fine grained seams. A few hundred yards from the hospital a quarry has been opened where the rock may be examined. The organic remains consist of broken shells and water-worn fragments of corals, which, both in species and state of preservation, resemble those on the shores of the island. Except in degree of hardness, the rock does not differ from the calcareous sands thrown up by the waves on the shore in the vicinity; and the conditions presented by the loose moving sands are not favourable to the habits of molluscous animals, nor are fossil shells very abundant in the limestone of the island. Oblique

or false stratification is everywhere seen in the rock, the inclination of the planes differing very little from the slope of the shore up which the waves push dead shells, pieces of coral, &c. After a breeze, coarse materials are found strewing the beach, a light wind leaves a finer deposit, and in the succeeding calm the sea appears milky from fine calcareous matter suspended in the water; this is deposited in the form of free, impalpable mud, which invests marine plants and other objects, to which it adheres with great tenacity, and becomes a source of annoyance to the collectors of Algæ. All these alternations of fine and coarse materials may be observed in the limestone. [The rock corresponds to the beach sand-rock.]

"Along the south beach, the sand is thrown up by the waves to an elevation nearly equal to that of the highest point of the island, and during the gale of Oct. 1841 the greater part of it was submerged, so that, at first sight, it might appear that the whole island was the result of sand thrown up at such times. But although I observed no beds in the limestone that prove, like those of our Tertiary, that the animals, whose remains they contain, lived and died on the spot, yet in its structure it shows the result of long-continued, steady wave-work that cannot be referred to any other cause.

"On Key West I found in the rocks no beds of coral retaining their original position, although large fragments are scattered through the mass.

"Some of the small Keys, such as the Mangrove Keys, are the result of gradual deposition of sedimentary matter, and many of those interspersed among the larger islands have not yet reached the level of high water, but are nevertheless covered by a dense growth of this curious tree. It would be difficult to imagine a plant better adapted to island-making than the mangrove. Its long pendulous seeds fall into the shallow water, stick in the soft mud, and take root; the bud proceeding from the opposite extremity, soon shoots up above water and sends down branches almost perpendicularly into the mud; these take root and produce other trees, and so on. Besides these, lateral shoots are given off, and, at a distance of

three or four feet, enter the water and take root; from the part above water others proceed and take a similar stride, and in this way they often travel twenty or thirty yards from the parent stem. Seaweeds and drift-wood become entangled among the stems, and very soon a permanent island is formed. Such islands are generally found under the lee of the Keys.

"But the greater number, if not all the Keys, rest upon a foundation of corals. At Sand Key, large rugged masses of dead coral are seen bordering the Key on the windward side, and rising above low water; similar masses may be seen at Sambo Key, and at other places along the outer reef. But the Keys within this barrier present better opportunities for studying the foundation upon which they rest. At Key Vacca, corals rise to a height of four feet above high water, and present not the slightest evidence of disturbance, beyond the upward movement which raised them to their present position. The rocky mass of coral along the margin of the Key is undermined by the waves, and otherwise worn into singularly rugged shapes, with sharp projecting points. Even at some distance from the water, bunches of coral project above the surface wherever the overlying sand is washed away.

"On Bahia-honda similar appearances are presented, where the coral rocks extend seaward; on the lee of the island a long sand-bank is thrown up, and a lagoon of considerable extent is formed, in which the mangrove-tree is seen striding about in the soft mud. This island was washed in two by the last hurricane, and the channel formed has three feet of water at low tide. In the shallow water off many of the Keys, very beautiful patches of Algæ, interspersed with living corals, are seen within six or eight inches of the surface. Off Indian and Plantation Keys, dark knobs of coral are visible upon the white mud of the bottom, which render the navigation amongst these Keys dangerous. On lower Matacumba I traced the rugged coral rocks for a mile in extent; I also found them on Conch Key, as I did indeed on nearly every island that I examined, where a section could be found on the shore, from which the overlying sands were washed."

Professor Agassiz gives the following general account of the Keys and Reefs (see also map):—

"The Keys consist of an extensive range of low islands, rising but a few feet, perhaps from six to eight or ten, or at the utmost to twelve or thirteen feet, above the level of the sea. They begin to the north of Cape Florida, when they converge toward the main land, extending in the form of a flat crescent in a south-westerly direction, gradually receding from the mainland until, opposite Cape Sable, they have so far retreated as to be separated from it by a shallow sheet of water forty miles wide. Further to the west they project in a more westerly course, with occasional interruptions, as far as the Tortugas [in longitude 83° W.], which form the most western group. They consist either of accumulated dead corals, of coral rocks, or of coral sand, cemented together with more or less compactness. Their form varies, but is usually elongated and narrow, their greatest longitudinal extent following the direction of the main range, except in the group of the Pine Islands, where their course is almost at right angles with the main range—a circumstance which we shall hereafter attempt to explain.

"Most of these islands are small, the largest of them, such as Key West, and Key Largo, not exceeding ten or fifteen miles in length; others only two or three, and many scarcely a mile. Their width varies from a quarter to a third or half a mile, the largest barely measuring a mile across; but whatever the difference in their size, they all agree in one respect—that their steepest shore is turned toward the Gulf Stream, while their more gradual slope inclines toward the mud flats which they incircle.

"This is a point which it is important to notice, as it will assist us in the comparison between the Keys and the shore bluffs of the mainland, as well as with the outer reef and reefs of other seas, in all of which we find that the seaward shore is steeper than that turned toward the mainland, or, in case of circular reefs inclosing basins (atolls), than that which borders the lagoon.

"The reef proper extends parallel to the main range of Keys, for a few miles south or south-west of it, following the same curve and never receding many miles from it. The distance between the reef and the main range of Keys varies usually from six to two or three miles, the widest separation being south of Key West, and east of the Ragged Keys, where the space is about seven miles. Between this reef, upon which a few small Keys rise at distant intervals, and the main range of Keys already described, there is a broad navigable channel, extending the whole range of the reef from the Marquesas to Cape Florida, varying in depth from three to six fathoms; and except Love Key, where the passage is not more than fourteen feet deep at low water, averaging from three to four fathoms.

"Further east the average depth is again the same as at Love Key, but it becomes gradually more and more shoal toward the east, measuring usually about two fathoms or even less to the east of Long Key and Key Largo, but deepening again somewhat toward Cape Florida, where the reef converges toward the main Keys and mainland. Protected by the outer reef, this channel affords a very safe navigation to vessels of medium size, and would allow a secure anchorage almost everywhere throughout the whole length of the reef, were the numerous deep channels which intersect the outer reef well known to navigators, and marked by a regular system of signals. As it is, however, the reef seems to present an unbroken range of most dangerous shoal grounds, upon which thousands of vessels, as well as millions of property, have already been wrecked. These facts have a stronger claim upon the attention of the Government, since there are, as already remarked, numerous passages across the reef, which might enable even the largest vessels to find shelter and safe anchorage behind this threatening shallow barrier. . . .

"The reef proper, as we have remarked above, runs almost parellel to the main range of Keys from Cape Florida to the western extremity of the Marquesas, where it is lost in the deep. It follows, in its whole extent, the same curve as the

Keys incircling, to the seaward, the ship-channel already mentioned. This is properly the region of living corals.

"Throughout its whole range it does not reach the surface of the sea, except in a few points where it comes almost within the level of low-water mark, giving rise to heavy breakers, such as Carysfort, Alligator Reef, Tennessee Reef, and a few other shoals of less extent, but perhaps not less dangerous. In a few localities, fragments of dead coral, and coral sand begin to accumulate upon the edge of the reef, forming small Keys, which vary in form and position according to the influence of gales blowing from different directions—sometimes in the direction of the Gulf Stream from south-west to north-east, but more frequently in the opposite direction, the prevailing winds blowing from the north-east. Such are Sombrero Key, Love Key, the Sambos and Sand Key. Here and there are isolated coral boulders, which present projecting masses above water, such as the Dry Rocks west of Sand Key, Pelican Reef, east of it, with many others more isolated. Though continuous, the outer reef is, however, not so uniform as not to present many broad passages over its crest, dividing it, as it were, into many submarine elongated hillocks, similar in form to the main Keys, but not rising above water, and in which the depressions alluded to correspond to the channels intersecting the Keys. The broad passages leading into the ship-channel, which may be available as entrances into the safe anchorage within the reef, are chiefly the inlet in front of Key Largo, and to the west of Carysfort reef, with nine feet of water; a passage between French reef and Pickle reef, with ten feet; another between Conch reef and Crocus reef, also with ten feet; another between Crocus reef and Alligator reef, with two fathoms; another between Alligator reef and Tennessee reef, with two fathoms and a half; and a sixth to the west of Tennessee reef varying in depth from two-and-a-half to three fathoms."

Through the labours of Mr. de Pourtales, in connection with the soundings by the Coast Survey, interesting facts have been brought to light respecting the sea between the

Florida reefs and the opposite shores or reefs along the Bahamas and Cuba, called the Straits of Florida. A few paragraphs on these straits by Mr. de Pourtales are cited from his memoir referred to on page 167. The places described will be found on the map at the close of this volume.

"In transverse sections of the channel, the greatest depth is nearest its southern or eastern shore, and in a longitudinal section the depth diminishes in passing toward the north, finding its minimum in the narrowest part between Cape Florida and the Bemini Islands, after which it increases again. In a transverse section between Key West and Havana, the greatest depth is 853 fathoms; between Sombrero Light and Elbow or Double-Headed Shot Key, on the Salt Key Bank, 500 fathoms; between Carysfort reef and Orange Key, on the Great Bahama Bank, 475 fathoms; and between Cape Florida and the Bemini Islands, 370 fathoms. In following a cross section from the emerged coral reef called the Florida Keys, the so-called Hawk Channel is first crossed, limited outside by the living coral reef. Its greatest depth is seldom more than six or seven fathoms, generally much less toward its northern extremity; it is often interrupted by shoals, and so-called heads of live coral, and its bottom consists of calcareous mud from decomposed corals and corallines. Next comes the reef, rising nearly to low-water mark, but by no means continuous. It extends from Cape Florida, south and west, to a short distance from beyond Key West, and seems to be slowly increasing in that direction.

"Although the deep blue colour of the water after passing the reef seems to indicate a very abrupt slope, there is in no part of it anything to compare with the sudden deepening on the edge of the coral reefs of the Pacific Ocean, or even of the Bahamas or the coast of Cuba. The distance from the reef to the 100-fathom line is not less than three miles, and often as much as six. In this space the bottom consists of calcareous mud, and is not particularly rich in animal life. From ninety or a hundred fathoms to two hundred and fifty or three hundred, the bottom slopes rather gently in the

shape of a rough rocky floor, without great inequalities; this formation obtains its greatest breadth, of about eighteen miles, a little to the east of Sombrero Light, and tapers off to the west, where it ends in about the same longitude as the end of the reef; toward the east and north it approaches nearer the reef, and ends gradually between Carysfort reef and Cape Florida. This bottom, which is called 'Pourtales Plateau' in Prof. Agassiz's report (see map), is very rich in deep-sea corals, the greatest number of those described in these pages [the memoir here cited from] having been dredged on this ground.

"Outside of the rocky bottom the Globigerina mud prevails and fills the trough of the channel.

"On the Cuba shore the bottom is rocky and the slope very abrupt, particularly for the first four or five hundred fathoms. Along the Salt Key and Bahama Banks, the slope is also exceedingly abrupt, but the underlying rock is often covered with mud."

Prof. Agassiz observes that the rocky bottom of the Pourtales Plateau is a true coral-rag—in other words, ordinary coral reef-rock—being made up of an agglomeration of fragments of corals and sand, cemented into a solid limestone.

Bahama Islands.—The Bahamas (the western margin of which is shown on the map of the Florida Reefs) are coral reefs and reef islands, essentially like atoll reefs. The northern end of the group lies opposite southern Florida, and from this point they stretch off to the west of south-west in a double series, nearly parallel to the trend of Cuba and San Domingo, and terminate properly in Turk's Island and some other reefs north of the latter,—the whole length above 600 miles. The 100-fathom line of soundings extends around the two northern ranges of reefs and islands, which, therefore, make up one bank, the Little Bahama Bank; and another similar line embraces the next six islands as parts of a second bank, called the Great Bahama Bank, whose whole length is about 300 miles. New Providence Island, the site of the seat of government of the group, Nassau, is the middle one of the three northern islands of this bank. The relation of

the eastern and western ranges of land in this Great Bank is really analogous to that of the opposite sides of the great Maldive Atoll Group. The remaining islands and reefs are mostly isolated. In the triangular interval between the Great Bahama Bank, Florida and Cuba, lies the reef called Salt Key Bank. The northern coast of Cuba, south of this bank, and to the eastward, is bordered by coral reefs.

The following are notes from an abstract of a paper presented to the Geological Society in 1852, by Major-General R. J. Nelson, R.E., and published in the Quarterly Journal of the Society for 1853, p. 200:—

"The loftiest land in the Bahamas, according to the maps of the Hydrographical Office, is only 230 feet above the sea. Generally speaking, the hills on the larger islands are much under 100 feet in height, and on the islets from 50 to 10 feet. . . . . The surface generally is occupied by low rocky hills, either surrounding basins or forming parts of what may once have been basins, and rarely by distinct hill and valley of the ordinary character. The bottoms of these basins are usually flat and rocky, only a few inches above the average high-water level, and have a rough and cavernous surface. Water, more or less brackish, rises and falls everywhere throughout the lower parts of these flats, though not contemporaneously with the tide,[1] or at a uniform rate. The surface is sometimes covered with grass and low bush, and sometimes it consists of the bare rock, full of hollows, which are coated or even arched over with sub-stalagmitic substance. It is in these cavities, locally termed 'pot-holes,' that most of the soil is found; and in the gardens made on such ground, fruit-trees, pine-apples, Indian corn, sugar-cane, &c., grow luxuriantly. Besides these 'rock-marshes' there are also ordinary marshes and mangrove swamps, of no great extent or depth, which are more or less in connection with the sea. On the larger islands the rocky surface of the hills is very thinly and partially covered with 'red earth,' mixed in varying proportions with

[1] At Nassau, Bahamas, the tide rises from 4 to 3 feet (spring to neap); but at Bermuda it rises from 6 to 4½.

vegetable matter. This scanty soil is fertile, if well used. When uncleared, it is covered with bush and forest trees. There are also sandy tracts termed 'pine-barrens,' where the bush suddenly disappears and the palmettos become fewer in number, though enough remain to exhibit an intermixture of pines and palms, respectively typical of the northern and southern floras. The lowest portions of the flat grounds frequently contain small brackish water or salt lakes. In the chalk-marsh of Andros Island, however, there is a freshwater lake, with three streams as its outlets; and it appears that there is no other freshwater lake or stream in the Bahamas. . . . . There are large caverns in Long Cay and Rum Cay; and probably caverns are as numerous in the Bahama Islands as in the Bermudas; but so few extensive excavations have been made, that this cannot be positively affirmed. . . . . One of the most striking objects in the topography of the Bahamas is the very deep submarine valley forming the gulf known as 'the Tongue of the Ocean,' which runs into the Great Bahama Bank from its northern end. The colour of the water around the islands is usually that of the *aqua-marine* variety of beryl; but the water of the Tongue of the Ocean has the deep blue colour of oceanic depths.

"The author describes a coral-reef as consisting of masses of numerous species of *Madrepora*, *Astræa*, *Dædalea*, *Oculina*, bases and axes of *Gorgonia*, *Millepora*, *Nullipora*, *Corallinæ*, &c. &c., growing confusedly together without any other apparent order than that of accidental succession and accretion, both laterally and vertically. These are at times aided or even superseded by *Serpulæ*, &c., as seen in the serpuline reefs. . . .

"Captain Nelson points out a few of the localities that exhibit most clearly the character, source, and mode of aggregation of the materials of the ordinary Bahama rock, such as is formed above the sea-level; at the same time referring to the illustrative specimens in the Bahama collection. For instance: the south side of Silver Cay and the beach extending westward from Nassau afford rolled blocks, pebbles, and sand derived from the massive corals, mixed with remains of turtles, fish,

crustaceans, echinoderms, and mollusks. On the beach between Clifton Point and West Bay (specimen No. 1) the shells of *Strombus gigas* more especially accompany the rolled corals. At East Point (specimens Nos. 2 and 3) the sand is derived from corallines and nullipores; the finer sand being often in approximately spherical grains, though not so perfectly as at the White Cay (specimen No. 4) and between Exuma and Long Cay. The beach near Charlotteville Point (specimen No. 5) consists principally of *Lucina Pennsylvanica* in various stages of comminution. At Six Hills (Caicos Group) the mass of Conch shells (*Strombus gigas*) is so great and sufficiently cemented together as to form not only rock, but an island several hundred feet in length. Along the N.W. beach at Gun Cay (specimen No. 8), a hard, coarse, stratified rock is formed of Conch and other shells, together with coral fragments.

"The large fragments of corals and shells are never found much beyond the surf-range of high-tide, and therefore always form rock at a low level; whilst on the contrary, the fine calcareous sand is removed by the wind and deposited in irregularly laminated beds, which, being consolidated in various degrees, are converted into rock of different qualities. . . . The ordinary Bahama rock everywhere consists of the above-mentioned calcareous sandstone. It is somewhat similar to Portland stone in appearance, but softer and more porous. When first exposed it is quite white, and is inconveniently bright and dazzling under a tropical sun; but it becomes of a dark ashen-grey colour along the sea-coast, and more or less so elsewhere, when exposed to the weather. Its average weight, like that of the Bermuda stone, varies from 95 to 145 pounds per cubic foot. Its inferior value as a building material arises from the numerous sand-flaws (specimen No. 7), and consequent ready failure when exposed to the weather. About the south-west of New Providence, for some feet above the sea, the rock is hard and homogeneous, and may be raised in good blocks for building purposes. The looser and softer kinds of rock are found usually on the hill tops. A variety offering a singular counterfeit of true oölitic structure is found at or near White Cay,

Exuma, and elsewhere; but the spherules are solid, and have been derived apparently from the stems of corallines. . . . A chalk-deposit is to be found, by all accounts, in the different basins or lagoon bottoms in every principal group, though nowhere so extensively as along the western coast of Andros Island, where it may almost be termed *a young chalk formation.* . . .

"The 'red earth' previously mentioned as forming, generally speaking, the scanty soil of the Bahamas, is at times interstratified with the rock, and sometimes it is incorporated with it. It is identical with the 'red earth' of the Bermudas (specimen No. 15) which proved a considerable source of embarrassment, especially with reference to Ireland Island, by seeming to point out alternations of aqueous and other deposits, which were contradicted by the presence of the characteristic *Helix* in all the beds. In visiting a cave near Delaport in 1849, Capt. Nelson found the bottom of the cave for many feet in depth covered with a loose dry 'red earth,' in grains varying in size from coarse sand to fine dust (specimens 14 and 14 *a*, *b*). Under the microscope this appeared as a mass of insect-remains, the *rejectamenta* of bats living in these caverns. Specimens of the earth from another part of the same cave, however, were so much altered in character, that they resembled the Bermuda 'red earth,' and afforded a complete clue to the characters of this substance. Some of the varieties from the Delaport cave were examined microscopically and chemically by Professor Quekett, of the Royal College of Surgeons, who not only confirmed the above, but announced that all the varieties gave off ammonia, whether retaining organic texture or not. The author thinks it not unlikely that the 'red earth,' even in the case of the five strata in Ireland Island, has been largely derived from bats inhabiting once-existing caverns; at the same time, he considers it probable that birds, their droppings supplying a sort of guano, have also assisted in the formation of this deposit.

"The occurrence of pumice floated ashore at Watling Island, and elsewhere in the Bahamas, is briefly noticed."

Prof. Agassiz gives the following account of a part of these reefs in the first volume of the "Bulletin of the Museum of Comparative Zoölogy:"—

"The Bahamas and the reefs to the north-east of Cuba exhibit very abrupt slopes, and a great depth is reached close to the shores of the Banks, so that the Bahamas resemble the coral reefs of the Pacific much more than the reefs of the coast of Florida.

"The whole group of banks and keys embraced between Double-Headed Shot Key, Salt Key, and Anguilla Key (all on the Salt Key Bank) is a very instructive combination of the phenomena of building and destruction. The whole group is a flat bank covered by four or five, and occasionally six, fathoms of water, with fine sandy bottom, evidently corals reduced to oölitic, the grains, which are of various sizes, from fine powder to coarse sand, mingled with broken shells, among which a few living specimens are occasionally found. The margin of the Bank is encircled on several points by rocky ridges of the most diversified appearance, and at others edged by sand-dunes. A close examination and comparison of the different Keys show that these different formations are in fact linked together, and represent various stages of the accumulation, consolidation, and cementation of the same materials. On the flat top of the bank the loose materials are pounded down to fine sand; in course of time this sand is thrown up upon the shoalest portions of the Bank, and it is curious to notice that these shoalest parts are its very edge, along which corals have formed reefs which have become the basis of the dry Banks. The foundation rock, as far as tide, wind, and wave may carry the coarser materials, consist of a conglomeration of coarser oölitic grains, rounded fragments of corals, or broken shells, and even larger pieces of a variety of corals and conchs, all the species being those now found living upon the Bank, among which *Strombus gigas* is the most common besides that, *Astræa* (*Orbicella*) *annularis*, *Siderastræa siderea* and *Mæandrina mammosa* prevail. The shells of Strombus are so common that they give great solidity and hardness to the rock.

The stratification is somewhat irregular, the beds slanting toward the sea at an angle of about seven degrees. Upon this foundation immense masses of Strombus, dead shells, and corals have been thrown in banks, evidently the beginning of deposits similar to those already consolidated below; but there is this difference in their formation, namely, that while the foundation rock is slightly inclined, and never rises above the level of high water, the accumulation of loose materials above water-level forms steeper banks, varying from fifteen to twenty and thirty degrees. In some localities broken shells prevail; in others coarse and fine sand; and the ridges thus formed, evidently by the action of high waves, rise to about twelve and fifteen feet. This is evidently the foundation for the accumulation of finer sand driven by the wind over these ridges, and forming high sand-dunes, held together by a variety of plants, among which a trailing vine (*Batatas littoralis*), various grasses and shrubs are the most conspicuous. These dunes rise to about twenty feet; on their lee side and almost to their summits grow a little palmetto. The sand of the dunes is still loose, but here and there shows a tendency to incrustation at the surface. The slope of these dunes is rather steep, sometimes over thirty degrees, and steeper to the seaward than on the landward side.

"In the interior of Salt Key there is a pool of intensely salt water, the tint of which is pinkish or flesh-coloured, owing to the accumulation of a small alga. When agitated by the wind, this pool is edged all around by foam of the purest white, arising from the frothing of the viscous water. Along the edge the accumulation of this microscopic plant forms large cakes, not unlike decaying meat, and of a very offensive odour. The foundation rock of this Key is exactly like what Gressly described as the '*facies corallien*' of the Jurassic formation; while the deposit in deep water, consisting chiefly of muddy lime particles, answers to his '*facies vaseux*.'

"Double-Headed Shot Key is a long, crescent-shaped ridge of rounded knolls, not unlike '*roches moutonnées*,' at intervals interrupted by breaks, so that the whole looks like a dismantled

wall, broken down here and there to the water's edge. The whole ridge is composed of the finest oölite, pretty regularly stratified, but here and there like torrential deposits; the stratification is more distinctly visible where the rocks have been weathered at the surface into those rugged and furrowed slopes familiarly known as 'karren' in Switzerland. It is plain that we have here the same formation as on Salt Key, only older, with more thoroughly cemented materials. The uniformity in the minute grains of the oölites leaves no doubt that the sand must have been blown up by the wind, and accumulated in the form of high dunes before it became consolidated. The general aspect of Doubled-Headed Shot Key is very different from that of Salt Key. The whole surface is barren—not a tree, hardly a shrub, and the scantiest creeping vegetation. The rock is very hard, ringing under the hammer, and reminds one of the bald summits of the Jura, such as Tête-de-Rang, near La-Chaux-de-Fond. It is evident that what is beginning on Salt Key has here been not only completed, but is undergoing extensive disintegration in Double-Headed Shot Key, both by the action of atmospheric agents over the surface and by the action of tides and winds against the base of the Key.

"Among these older oölitic deposits, forming the main range of Orange Key, and of Double-Headed Shot Key, we recognize formations of more recent date, occupying the cavities of ancient pot-holes, which have been gradually filled with materials identical with those of the older deposits. The pot-holes themselves show nothing very peculiar; there are many such upon these Keys—some large ones many yards in diameter, and others quite small—evidently formed by the wearing action of loose pieces of harder coral rocks thrown upon the Key by great waves, and only occasionally set in motion by the waters dashing over the Keys during heavy storms. The pot-holes nearest the water's edge are the most recent, and are mostly clean excavations, either entirely empty or containing sand and limestone pebbles lying loose at the bottom of the holes. Some of these excavations are circular; others oblong; still others have the form of winding caves

opening toward the sea, or upon the surface of the Key. Beyond the reach of ordinary tides, and of the waves raised by moderate winds, the pot-holes are generally lined with coatings of solid, compact, and hard limestone, varying from a thin layer to a deposit of several inches in thickness, and following all the sinuosities of the cavities in which they are accumulating. It is plain from their structure that these coatings are a sub-aerial formation, increasing by the successive accumulations of limestone particles left upon the older rock by the evaporation of water thrown upon the Key when the ocean is so violently agitated as to dash over the whole Key. Frequently the hollow of these coated pot-holes is further filled with consolidated oölite; or thin layers of fine-grained oölite alternate with a coat of compact limestone, throughout the excavation, which often has been filled in this way up to the general level of the surrounding surface. Occasionally these regenerated surfaces are again hollowed out by the action of storms, and the result is a dismantled pot-hole, in which their structure and the mode of their filling is distinctly exhibited.

"The stratification of the main mass of these Keys is very peculiar. Though evidently the result of an accumulation of oölites through the action of high waves, the beds are pretty regular in themselves, but slant in every direction toward the sea, showing that they were deposited under the action of winds blowing at different times from every quarter. It is further noteworthy, that, while the thicker layers consist of oölitic grains distinguishable by the naked eye, there are at intervals thin layers of very hard, compact limestone, alternating with the oölitic beds, which have no doubt been formed in the same manner as the coating of the pot-holes."

The oölitic limestones, referred to by Prof. Agassiz as the description states, are not the true coral reef-rock, the basement rock of the reefs, but the superficial beach sand-rock and drift sand-rock of the preceding pages, which are very generally oölitic in structure.

The Bermuda or Somers' Islands.—The Bermudas are the parts of a single atoll, as first announced by Major-General (then

Lieut.) Nelson, R.E., in his paper in the Transactions of the Geological Society of London, vol. v. 1840); and this atoll is the most remote from the equator of any existing. It lies between the parallels 32° and 32° 35′, and the meridians 65° 45′ and 66° 55′. It is a *living* coral reef; the principal species of corals are mentioned on page 88.



THE BERMUDA ISLANDS.

The general form and position of the reef and its islets are shown in the accompanying map. The longer diameter of the elliptical area trends nearly north-east-by-east, and is about twenty-five miles in length, while the transverse diameter is about fifteen miles.

Although an elevated atoll, the emerged land—about fifteen miles in length—is confined to the side facing south-east, excepting a single isolated rock on the north (between *c* and *d*

in the map), called North Rock. It is broken into a hundred and fifty or more islets—in consequence partly of degradation since the elevation, and partly of the unequal height of the reef formation before its elevation. The surface is made up of hills and low basins. The highest point, Sears' Hill (E), is, according to Lieut. Nelson, 260 feet in elevation above the sea, and Gibbs Hill (D), the site of the lighthouse, 245 feet. Wreck Hill (F), near the western point of the principal island, is about 150 feet high, and North Rock is 16 feet high. H is the position of Hamilton, the seat of Government, and G of St. George's, the other principal town. A (Castle Harbour), B (Harrington Sound), and C (Great Sound), are three encircled bays, looking as if once the lagoons of sub-atolls in a Maldive-like compound atoll. The surface about half way between the sounds A and B is low. Most of the land is covered with cedar-trees, where not cultivated or given over to loose sand.

The rock of the surface is described as a calcareous sand-rock, analogous evidently to the beach sand-rock and drift sand-rock. Toward the shores the solid reef-rock outcrops—a hard, white limestone. Lieut. Nelson speaks of that on St. George's Island as a "very hard, fine-grained or compact limestone, in which scarcely a vestige of organic structure is to be seen." In one place he observed a Mæandrina (Diploria) four feet above high-tide level.

The soil is calcareous, modified by vegetation, and in part, according to Lieut. Nelson, "a dry, aluminous earth." The same observer mentions the occurrence on the land of oxide of iron and manganese, and of some titanic iron; but Mr. J. Matthew Jones states (*Canadian Naturalist*, Feb. 1864) that all stones not of coral and shell origin have undoubtedly been brought in the roots of drift-trees; and the West Indies were probably their source.

The greater part of the old atoll is still a submerged reef. Its outer border is mostly from one to three fathoms under water at low tide, though in some parts laid bare at the ebb. It has open channels at *a* (called the Chub cut), *b* (Blue cut, shallow), *c* (N. W. Channel), *d* (N. E. Channel), *e* (Mills'

Breaker Channel), *f* (the Channels affording the nearest routes to Murray Anchorage and St. George's Harbour), *g* (Channel by St. David's Head, shallow), and *h* (Hog-fish cut). The reef-grounds, inside, are encumbered with countless clumps of corals and coral-heads, one to four fathoms under water with intervals between of five to ten fathoms; some large tracts are without corals, and these have a nearly uniform depth of seven or eight fathoms. To a vessel entering, the positions of the coral clumps are made known by the brownish or discoloured water above them. The bottom, over large areas, is a calcareous clay or mud; that of Murray Anchorage, a fine chalky clay.

The wind for three-fourths of the year is from the south-east or south-west, and this may in part account for the south-east side of the atoll being highest. But this feature is probably owing much to the configuration of the land upon which the coral reefs were built up. The reefs along the south-east and south sides are narrow, not over a fourth of a mile wide, and the waters abruptly deep; and consequently we may conclude that this south-eastern side of the original island was bold and high, while off to the north the surface was relatively low and flat.

Twenty miles south-west-by-west from the Bermudas there are two submerged banks or shoals, both reported as having a "corally and rocky bottom;" one has 22 to 40 fathoms over it, and the other 33 to 47 fathoms. Dredging on these banks might make some interesting disclosures.

The following observations bearing on the question as to the former extent of the Bermudas group are from a paper by Mr. S. Matthew Jones, in *Nature*, August 1872:—

"As my late visit to the Bermudas has placed me in possession of facts relating to their original aspect of a somewhat conclusive nature, I deem it advisable to communicate such in a brief form, instead of awaiting the time requisite for the preparation of a more elaborate paper on the subject. On previous occasions I have always regretted my inability, from lack of time, to look more closely into their geological char-

acter in the hope of discovering some satisfactory clue to their primitive condition. I was aware that in different parts of the islands road cuttings and well borings had revealed layers of red earth at certain depths below the surface, the consistence of which was similar to that now forming the present surface soil; and it did not require much force of imagination, after personal inspection, to conceive that such layers of red earth were first formed by the decomposition of vegetable matter which grew upon former surfaces, and became covered to their respective depths by accumulated masses of drift sand, which from natural causes hardened into more or less compact sandstone. But these different layers were but a few feet beneath the surface, and so, although interesting as throwing light upon the gradual elevation of the land by drift material forming over them, yet they afforded no evidence of a contrary nature—viz. the *submergence* of the Bermuda group. Indeed, I have always been led to suppose from appearances that the whole group was the result of an upheaval of the ocean bed slightly above the water level, and a gradual elevation afterward by means of drift matter aided by the consolidating agency of reef-building zoophytes encircling the whole with a barrier reef, and by isolated patches gradually filling up the space within. The investigations, however, which I have recently been able to make, tend I think to prove that the barrier reef encircling the islands, which has hitherto been considered an atoll, is merely the remnant of the more compact calcareous rock which formed the shore of a much more extensive island group than that now existing.

"My views in this respect are borne out by the following facts:—The barrier reef, as far as I have inspected it, is merely ordinary calcareous rock coated with Serpulæ, Nullipores, &c., the reef builders working only in the sheltered waters between the reef and the shore in three to eight fathoms. About two years ago submarine blastings were carried on at the entrance of Hamilton Harbour, and at a depth of over six fathoms a cavern was broken into which contained stalactites and red earth. Again within the last few months, I have, through the

kindness of his Excellency Major-General Lefroy, C.B., F.R.S., the present Governor, been placed in possession of still more satisfactory information. During the past two years extensive submarine blastings have taken place inside an artificial harbour situated at the western extremity of the islands, for the purpose of forming a bed of sufficient depth for the reception of the 'Great Bermuda Dock,' which attracted so much attention off Woolwich when launched some three or four years ago. The excavations extended to a depth of fifty-two feet below low-water mark. At forty-six feet occurred a layer of red earth two feet in thickness, containing remains of cedar trees, which layer rested upon a bed of compact calcareous sandstone. Here we have the first satisfactory evidence of the submergence of an extensive deposit of soil once upon the surface, and that to the depth of forty-eight feet below the present low-water level, which consequently grants an equal elevation above it in former times. Now, on carefully surveying the Bermuda chart, we find that an elevation of forty-eight feet will bring the whole space which intervenes between the present land and the barrier reef, now covered with water, above the water level. This attained, what more is required to prove the former extent of the island group before the present submergence to the present barrier reef? But having clearly ascertained beyond doubt that the Bermudas were once forty-eight feet higher than at present, will any one be bold enough to deny them a greater elevation? I have reason to believe that they once extended in a south-westerly direction—not only out to the reef, but to a greater distance. There are some rocky ledges about twenty to twenty-five miles from land in that direction, known as 'The Flatts,' lying in about thirty-five to forty fathoms water; and, singularly enough, in the very oldest maps of the Atlantic, copies of which I have consulted in the British Museum, 'The False Bermudas' are put down about this position. Is it unreasonable to suppose that a low-lying group of islets did actually exist here in former times? Again, in Smith's 'History of Virginia,' which gives an excellent account of the islands in the early part of the seventeenth

century, it is stated, among other notes upon their natural history, that flocks of crows, no doubt the same species (*Corvus Americanus*) which now inhabits them, were in the habit every evening of winging their flight from the main island toward the north. This observation, which from its simplicity I should the more readily believe to be a true statement, would clearly prove the existence of land in that direction at no great distance; for the habit of this bird to leave its roosting-place for distant feeding-grounds during the day, to return at random, is one of its well-known characteristics.

"Taking these matters into consideration, I see everything to support the supposition that the Burmudas once presented a much more extensive aspect than they do at present; and certain additional evidences which I hope to bring forward shortly in a collected form will, I conceive, tend to confirm my impression that the restricted terraqueous area lying within the limits of the outer barrier reef is merely the summit of one of a range of islands which extended in somewhat semicircular form for a distance of seventy or eighty miles, and which have suffered submergence to a depth only to be correctly ascertained by borings, which might be successfully accomplished under the auspices of the Government at a trifling expense."

CHAPTER III.

FORMATION OF CORAL REEFS AND ISLANDS, AND CAUSES OF THEIR FEATURES.

I. FORMATION OF REEFS.

1. ORIGIN OF CORAL SANDS AND THE REEF-ROCK.

VERY erroneous ideas prevail respecting the appearance of a bed or area of growing corals. The submerged reef is often thought of as an extended mass of coral, alive uniformly over its upper surface, and as gradually enlarging upward through this living growth; and such preconceived views, when ascertained to be erroneous by observation, have sometimes led to skepticism with regard to the zoöphytic origin of the reef-rock. Nothing is wider from the truth: and this must have been inferred from the descriptions already given. Another glance at the coral plantation should be taken by the reader, before proceeding with the explanations which follow.

Coral plantation and coral field are more appropriate appellations than coral garden, and convey a juster impression of the surface of a growing reef. Like a spot of wild land, covered in some parts, even over acres, with varied shrubbery, in other parts bearing only occasional tufts of vegetation in barren plains of sand, here a clump of saplings, and there a carpet of variously-coloured flowers in these barren fields—such is the coral plantation. Numerous kinds of zoöphytes

grow scattered over the surface, like vegetation upon the land; there are large areas that bear nothing, and others of great extent that are thickly overgrown. There is, however, no green sward to the landscape; sand and fragments fill up the bare intervals between the flowering tufts: or, where the zoöphytes are crowded, there are deep holes among the stony stems and folia.

These fields of growing coral spread over submarine lands, such as the shores of islands and continents, where the depth is not greater than their habits require, just as vegetation extends itself through regions that are congenial. The germ or ovule, which, when first produced, is free, finds afterward a point of rock, or dead coral, or some support to plant itself upon, and thence springs the tree or other forms of coral growth.

The analogy to vegetation does not stop here. It is well known that the débris of the forest, decaying leaves and stems and animal remains, add to the soil; that in the marsh or swamp—where decaying vegetation is mostly under water, and sphagnous mosses grow luxuriantly, ever alive and flourishing at top, while dead and dying below,—accumulations of such débris are ceaselessly in progress, and deep beds of peat are formed. Similar is the history of the coral mead. Accumulations of fragments and sand from the coral zoöphytes growing over the reef-grounds, and of shells and other relics of organic life, are constantly making; and thus a bed of coral débris is formed and compacted. There is this difference, that a large part of the vegetable material consists of elements which escape as gases on decomposition, so that there is a great loss in bulk of the gathered mass; whereas coral is an enduring rock material undergoing no change except the mechanical one of comminution. The animal portion is but a mere fraction of the whole zoöphyte. The coral débris and shells fill up the intervals between the coral patches and the cavities among the living tufts, and in this manner produce the reef deposit; and the bed is finally consolidated while still beneath the water.

The coral zoöphyte is especially adapted for such a mode of reef-making. Were the nourishment drawn from below, as in most plants, the solidifying coral rock would soon destroy all life: instead of this, the zoöphyte is gradually dying below while growing above; and the accumulations of débris cover only the dead portions.

But on land, there is the decay of the year and that of old age, producing vegetable débris; and storms prostrate forests. And are there corresponding effects among the groves of the sea? It has been shown that coral plantations, from which reefs proceed, do not grow in the "calm and still" depths of the ocean. They are to be found amid the very waves, and extend but little below a hundred feet, which is far within the reach of the sea's heavier commotions. To a considerable extent they grow in the very face of the tremendous breakers that strike and batter as they drive over the reefs. Here is an agent which is not without its effects. The enormous masses of uptorn rock found on many of the islands may give some idea of the force of the lifting wave; and there are examples on record, to be found in various treatises on geology, of still more surprising effects.

During the more violent gales, the bottom of the sea is said, by different authors, to be disturbed to a depth of three hundred, three hundred and fifty, or even five hundred feet; and De la Beche remarks, that when the depth is fifteen fathoms, the water is very evidently discoloured by the action of the waves on the sand and mud of the bottom. M. Siau mentions (*Comptes Rendus* t. xii. 744) that ripple-marks are formed on the bottom by the motion of the water, which may be readily distinguished at a depth of at least twenty metres. The hollows between such ridges or zones are occupied by the heavier substances of the bottom. Similar ripple-marks were distinguished at a depth of one hundred and eighty-eight metres, to the north-west of the St. Paul's Roads.

In an article on the Force of Waves, by Thomas Stevenson, of Edinburgh, published in the Transactions of the Royal Society of Edinburgh (vol. xvi., 1845), it is stated as a deduc-

tion from two hundred and sixty-seven experiments, extending over twenty-three successive months, that the average force for Skerryvore, for five of the summer months, during the years 1843, 1844, was six hundred and eleven pounds per square foot; and for six of the winter months of the same years it was two thousand and eighty-six pounds per square foot, or three times as great as during the summer months. During a westerly gale, at the same place, in March, 1845, a pressure of six thousand and eighty-three pounds was registered by Mr. Stevenson's dynamometer (the name of the instrument used). He mentions several remarkable instances of transported blocks. One of gneiss, containing five hundred and four cubic feet, was carried by the waves five feet from the place where it lay, and there became wedged so as no longer to be moved. Of the manner in which it was moved, Mr. Reid (as cited by Mr. Stevenson) says: "The sea, when I saw it striking the stone, would wholly immerse or bury it out of sight, and the run extended up to the grass-line above it, making a perpendicular rise of from thirty-nine to forty feet above high-water level. On the incoming waves striking the stone, we could see this monstrous mass, of upwards of forty tons weight, lean landward, and the back-run would uplift it again with a jerk, leaving it with very little water about it, when the next incoming wave made it recline again."

Mr. Stevenson states also that the Bell Rock Lighthouse, in the German Ocean, though one hundred and twelve feet in height, is literally buried in foam and spray to the very top during ground swells, when there is no wind. On the 20th of November, 1827, the spray rose to the height of one hundred and seventeen feet above the foundations or low-water mark; and deducting eleven feet for the tide that day, it leaves one hundred and six feet, which is equivalent to a pressure of *nearly three tons per square foot.*

With such facts, any incredulity respecting the power of waves should be laid aside. Moreover, it may be remarked that the Pacific is a much wider ocean than the Atlantic, with far heavier waves in its ordinary state.

We must, therefore, allow that some effect will be produced upon the coral groves. There will be trees prostrated by gales, as on land, fragments scattered, and fragmentary and sand accumulations commenced. Besides, masses of the heavier
11 corals will be uptorn, and carried along over the coral plantation, which will destroy and grind down everything in their way. So many are the accidents of this kind to which zoöphytes appear to be exposed, that we might believe they would often be exterminated, were they not singularly tenacious of life, and ready to sprout anew on any rock where they may find quiet long enough to give themselves again a firm attachment.

But it should be observed, that the sea would have far less effect upon the slender forms characterizing many zoöphytes, among which the water finds free passage, than on the massive rock, against whose sides a large volume may drive unbroken. Moreover, much the greater part of the strength of the ocean is exerted near tide level, where it rises in breakers which plunge against the shores. Yet owing to the many nooks and recesses deep among the corals, the rapidly moving waters, during the heavier swells, must produce whirling eddies of considerable force, tending to uproot or break the coral clumps. These disrupting and transporting effects will be less and less as we recede from the shores; yet all coral depths must experience them in some degree.

There is another process going on over the coral field, somewhat analogous to vegetable decay, though still very different. Zoöphytes have been described as ever dying while living. The dead portions have the surface much smoothed, or deprived of the roughening points which belong to the living coral, and the cells are sometimes half obliterated, or the delicate lamellæ worn away. This may be viewed as one source of fine coral particles; and as the process is constantly going on, it is not altogether unimportant. This material is in a fit condition to enter into solution, and it cannot be doubted that the water receives lime from this source, which is afterward yielded to the reef.

In the Alcyonia family, which includes semi-fleshy corals, and in the Gorgoniæ, the lime is often scattered through the polyps in granules; and the process of death sets these calcareous grains free, which are constantly added to the coral sands. The same process has been supposed to take place in the more common reef corals, the Madrepores and Astræas, and it is possible that this may be to some extent the case. Yet it would seem, from facts observed, that after the secretion has begun within the polyp, the secretion of lime going on takes place *against* the portions already formed and in direct union with them, and not as granules to be afterward cemented.

The *mud-like* deposits about coral reefs (pp. 113, 149, 167) have been attributed to the causes just mentioned, but without due consideration. There is an unfailing and abundant source of this kind of material in the self-triturating sands of the reefs acted upon by the moving waters. On the seaward side of coral islands, and on the shores of the larger lagoons, where the surface rises into waves of much magnitude, the finer portions are carried off, and the coarser sand remains alone to form the beaches. This making of coral sand and mud is just like that of any other kind of sand or mud. It takes place on all shores exposed to the waves, coral or not coral, and in every case the gentler the prevailing movement of the water, the finer the material on the shore. In the smaller lagoons, where the water is only rippled by the winds, or roughened for short intervals, the trituration is of the gentlest kind possible, and, moreover, the finely pulverized material remains as part of the shores. Thus the fine material of the mud must be constantly forming on all the shores, for the sands are perpetually wearing themselves out; but the particles of the fine mud, which is washed out from the beach sands, *accumulates* only in the more quiet waters some distance outside of the reef, and within the lagoons and channels, where it settles. This corresponds exactly with the facts; and every small lake or region of quiet waters over our continent illustrates the same point.

Mr. Darwin, in discussing the origin of the finer calcareous mud (op, cit., p. 14), supposes that it is derived in part from fishes and Holothurians; and other authors have thrown out the same suggestion. He cites as a fact, on the authority of Mr. Liesk, that certain fish browse on the living zoöphytes; and from Mr. Allan, of Forres, he learned also that Holothurians subsisted on them. With regard to the facts here stated, no positive asertion can be made. Small fish swarm about the branching clumps, and when disturbed, seek shelter at once among the branches, where they are safe from pursuit. The author has often witnessed this, and never saw reason to suppose that they clustered about the coral for any other purpose. It is an undoubted fact, as stated by Mr. Darwin, that fragments of coral and sand may be found in the stomachs of these animals, but this is not sufficient evidence of their browsing on the coral. Fish so carefully avoid polyps of all kinds because of their power of stinging (as illustrated on p. 16), that we should wait for further and direct evidence on this point. The conclusion deduced by him from the facts, may be justly doubted. The fish and Holothurians, though numerous, are quite inadequate for the supply; and, moreover, we have, as explained above, an abundant source of the finest coral material without such aid. Motion of particle over particle will necessarily wear to dust, even though the particles be diamonds; and this incessant grinding action about reefs accounts satisfactorily for the deposits of coral mud, however great their extent.

The coral world, as we thus perceive, is planted, like the land with a variety of shrubs and smaller plants, and the elements and natural decay are producing gradual accumulations of material, like those of vegetation. The history of the growing reef has consequently its counterpart among the ordinary occurrences of the land about us.

The progress of the coral formation is like its commencement. The same causes continue, with similar results, and the reader might easily supply the details from the facts already presented. The production of débris will necessarily continue

to go on : a part will be swept by the waves, across the patch of reef, into the lagoon or channel beyond, while other portions will fill up the spaces among the corals along its margin, or be thrown beyond the margin and lodge on its surface. The layer of dead coral rock which makes the body of the reef, has its border of growing corals, and is thus undergoing extension at its margin, both through the increase in the corals, and the débris dropped among them.

But besides the small fragments, larger masses will be thrown on the reefs by the more violent waves, and commence to raise them above the sea. The *clinker fields* of coral by this means produced, constitute the first step in the formation of dry land. Afterward, by further contributions of the coarse and fine coral material, the islets are completed, and raised as far out of the water as the waves can reach—that is, about ten feet, with a tide of three feet ; and sixteen to eighteen feet with a tide of six or seven.

The Ocean is thus the architect, while the coral polyps afford the material for the structure ; and, when all is ready, it sows the land with seed brought from distant shores, covering it with verdure and flowers.

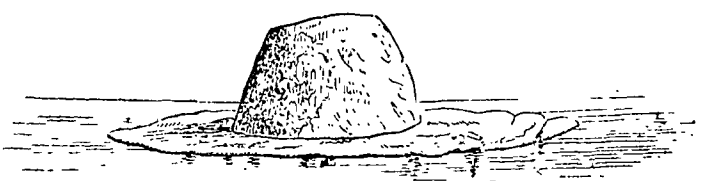
The growth of the reefs and islands around high lands is the same as here described for the atoll. The reef-rock is mainly a result of accumulations of coral and shell débris. There are reefs where the corals retain the position of growth, as has been described on a former page. But with these the débris comes in to fill up the intervening spaces or cavities, and make a compact bed for consolidation. There are other parts, especially portions of the outer reef along the line of breakers, which are formed by the gradual growth of layer upon layer of incrusting Nullipores ; but such formations are of small extent, and only add to the results from other sources.

II. ORIGIN OF THE SHORE PLATFORM.

Among the peculiarities of coral islands, the *shore platform* appears to be one of the most singular, and its origin has not

been rightly understood. It will be remembered that it lies but little above low-tide level, and it is often over three hundred feet in width, with a nearly flat surface throughout.

Though apparently so peculiar, the existence of this platform is due to the simple action of the sea, and is a necessary result of this action. On the shores of New South Wales, Australia, near Sydney, as observed by the author, the same structure is exemplified along the *sandstone* shores of this semi-continent, where it is continued for scores of miles. At the base of the sandstone cliff, in most places one or more hundred feet in height, there is a layer of sandstone rock, lying, like the shore platform of the coral island, near low-tide level, and from fifty yards in width. It is continuous with the bottom layer of the cliff: the rocks which once covered it have been removed by the sea. Its outer edge is the surf-line of the coast. At low-tide it is mostly a naked flat of rock, while at high tide it is wholly under water, and the sea reaches the cliff.



THE OLD HAT.

New Zealand, at the Bay of Islands, affords a like fact in an argillaceous sand-rock; and there was no stratification in this case to favour the production of a horizontal surface; it was a direct result from the causes at work. The shore shelf stands about five feet above low water. A small island in this bay is well named the "Old Hat," the platform encircling it, as shown in the above figure, forming a broad brim to a rude conical crown. The water, in these cases, has worn away the cliffs, leaving the basement untouched.

A surging wave, as it comes upon a coast, gradually rears itself on the shallowing shores; finally, the waters at top, through

their greater velocity, plunge with violence upon the barrier before it. The force of the ocean's surge is therefore mostly confined to the summit waters, which add weight to superior velocity, and drive violently upon whatever obstacle is presented. The *lower* waters of the surge advance steadily but more slowly, owing to the retarding friction of the bottom; the motion they have is directly forward, and thus they act with little mechanical advantage; moreover, they gradually swell over the shores, and receive, in part, the force of the *upper* waters. The wave, after breaking, sweeps up the shore till it gradually dies away. Degradation from this source is consequently most active where the upper or plunging portion of the breaker strikes.

But, further, we observe that at low-tide the sea is comparatively quiet; it is during the influx and efflux that the surges are heaviest. The action commences after the rise, is strongest from half to three-fourths tide, and then diminishes again near high tide. Moreover, the plunging part of the wave is raised considerably above the general level of the water. From these considerations, it is apparent that the line of greatest wave-action must be above low-water level. Let us suppose a tide of three feet, in which the action would probably be strongest when the tide had risen two feet out of the three; and let the height of the advancing surge be four feet:—the wave, at the time of striking, would stand, with its summit, three feet above high-tide level; and from this height would plunge obliquely downward against the rock, or any obstacle before it. It is obvious that, under such circumstances, the greatest force would be felt not far from the line of high tide, or between that line and three feet above it; moreover, the rise of the waters to half or two-thirds tide affords a protection against the breaker to whatever is below this level. In regions where the tide is higher than just supposed, as six feet for example, the same height of wave would give nearly the same height to the line of wave action, as compared with high-tide level. Under the influence of heavier waves, such as are common during storms, the line of wave-action would be at a still higher elevation, as may be readily estimated by the reader.

Besides a line of the *greatest* wave-action, we may also distinguish a height where this action is entirely null; and it is evident, from facts already stated, that the point will be found somewhat above low-tide level. The lower waters of the surge, instead of causing degradation, are *accumulative* in their ordinary action, when the material exposed to them is movable: they are constantly piling up, while the upper waters are eroding, and preparing material to be carried off. The height at which these two operations balance one another will be the height, therefore, of the line of no degradation. As the sea at low tide is mostly quiet, and the lower of the surging waters swell on to receive the upper and parry the blow, and moreover, there is next a return current outward, we should infer that the line would be situated more or less above low tide, according to the height of the tide and the surges accompanying it. We are not left to conjecture on this point; for the examples presented by the shores of Australia and New Zealand afford definite facts. Degradation has there taken place sufficient to carry off cliffs of rock, of great extent; yet below a certain level, the e has had little or no effect. This height, on the eastern shores of Australia, is three feet above ordinary low tide, and at New Zealand, above five feet. With regard to the height varying with the tides, we observe that in the Paumotus, where the water rises but two or three feet, the platform is seldom over four to six inches above low tide, which is proportionally less than at Australia and New Zealand, where the tide is six and eight feet. From these observations it appears that the height of no *wave-action*, as regards the degradation of a coast under ordinary seas, is situated near one-fifth tide in the Paumotus, and above half-tide at New Zealand, showing a great difference between the effect of the comparatively quiet surges of the middle Pacific, and the more violent of New Zealand. Within the Bay of Islands, where the sea has not its full force, the platform, as around the "Old Hat," is but little above low-water level. The exact relation of the height of the platform to the height and force of the tides, and the force of wave-action, remains to be determined more accurately by

observation. While, therefore, the height of the shore platform depends on the tides, and the degree of exposure to the waves, the breadth of it will be determined by the same causes in connection with the nature of the rock material.

On basaltic shores it is not usual to find a shore platform, as the rock scarcely undergoes any degradation, except from the most violent seas; such coasts are consequently often covered with large fragments of the basaltic rocks. But on sandstone shores, this gradual action keeps the platform of nearly uniform breadth. Moreover, any uptorn masses thrown upon it, are soon destroyed by the same action, and carried off; and thus the platform is kept nearly clean of débris, even to the base of the cliff.

It is apparent that one single principle meets all the various cases. The rocky platform of some sea-shores, the low tide sand-spits on others, and the coral reef platform of others, require but one explanation. The material of the coral platform is piled up by the advancing surges, and cemented through the infiltrating waters. These surges, advancing toward the edge of the shelf, swell over it before breaking, and thus throw a protection about the exposed rocks; and as the tide rises, this protection is complete. They move on, sweeping over the shelf, but only clear it of sand and fragments, which they bear to the beach.

The isolated blocks in the Paumotus which stand on the platform, attached to it below, are generally most worn one or two feet above high-tide level, a fact which corresponds with the statement in a preceding paragraph with regard to the height of the greatest wave-action.

III. EFFECTS OF WINDS AND GALES.

In addition to this ordinary wave-action, there are also more violent effects from storms; and these are observed alike on the Australian shores referred to, and on those of coral islands. The waters as they move in, first draw away and then drive on with increased velocity up the shallowing shores, or under shelving layers, and thus they easily break off great

rocks from the edge of the platform, and throw them on the reef. From the observations of Mr. Stevenson, cited on a preceding page (p. 191), it appears that the force of the waves during the summer and winter months differs at Skerryvore more than 1,200 pounds to the square foot,—in the former it averaging but 636 pounds, and in the latter 2,086 pounds, while in storms it was at times equivalent to 6,083 pounds. The seasons are not as unlike in the tropical part of the Pacific. Still there must be a marked difference between the ordinary seas and those during stormy weather. We have, therefore, no difficulty in comprehending how the ordinary wave-action should build up and keep entire the shore platform, while the more agitated seas may tear up parts of the structure formed, and bear them on to the higher parts of the island. Still more violent in action are the great earthquake-waves, which move through the very depths of the ocean.

These principles offer an explanation also of the general fact that the windward reef is the highest. The ordinary seas both on the leeward and windward sides, are sufficient for producing coral débris and building up the reef, and in this work the two sides will go on together, though at different rates of progress. We may often find no very great difference in the *width* of the leeward and windward reefs, especially as the wind for some parts of the year, has a course opposite to its usual direction. But seldom, except on the side to windward, is a sufficient force brought to bear upon the edge of the platform, to detach and uplift the larger coral blocks. The distance to which the waves may roll on without becoming too much weakened for the transportation of uptorn blocks, will determine the outline of the forming land. With proper data as to the force of the waves, the tides, and the soundings around, the extent of the shore platform might be made a subject of calculation.

The effect of a windward reef in diminishing the force of the sea, is sometimes shown in the influence of one island on another. A striking instance of this is presented by the northernmost of the Gilbert Islands (see map on page 133). All the islands of this group are well wooded to windward—

the side fronting east. But the north and north-east sides of Tari-tari are only a bare reef, through a distance of twenty miles, although the south-east reef is a continuous line of verdure. The small island of Makin, just north of Tari-tari, is the breakwater which has protected the reef referred to from the heavier seas.

Coral island accumulations have an advantage over all other shore deposits, owing to the ready agglutination of calcareous grains, as explained on a following page. It has been stated that coral sand-rocks are forming along the beaches, while the reef-rock is consolidating in the water. A defence of rock against encroachment is thus produced, and is in continual progress. Moreover, the structure built amid the waves will necessarily have the form and condition best fitted for withstanding their action. The atoll is, therefore, more enduring than hills of harder basaltic rocks. Reefs of zoöphytic growth but "mock the leaping billows," while other lands of the same height gradually yield to the assaults of the ocean. There are cases, however, of wear from the sea, owing to some change of condition in the island, or in the currents about it, in consequence of which, parts once built up are again carried off. Moreover, those devastating earthquake-waves which overleap the whole land, may occasion unusual degradation. Yet these islands have within themselves the source of their own repair, and are secure from all serious injury.

The change of the seasons is often apparent in the distribution of the beach sands covering the prominent points of an island. At Baker's Island (near the equator, in long. 176° 23′, W.) this fact is well illustrated. J. D. Hague states (*Am. Jour. Sci.*, II., xxxiv. 237), that the shifting sands change their place twice a year. "The western shore of the island trends nearly north-east and south-west; the southern shore, east-by-north. At their junction there is a spit of sand extending out toward the south-west. During the summer, the ocean swell, like the wind, comes from the south-east, to the force of which the south side of the island is exposed, while the western side is protected. In consequence, the sands of the beach that have been accu-

mulating during the summer on the south side, are all washed around the south-west point and are heaped up on the western side, forming a plateau along the beach two or three hundred feet wide, nearly covering the shore platform, and eight or ten feet deep. With October and November comes the winter swell from the north-north-east, which sweeps along the western shore, and from the force of which the south side is in its turn protected. Then the sand begins to travel from the western to the southern side; and, after a month or two, nothing remains of the great sand plateau but a narrow strip; while on the south side, the beach has been extended two hundred or three hundred feet. This lasts until February or March, when the operation is repeated."

II. CAUSES MODIFYING THE FORMS AND GROWTH OF REEFS.

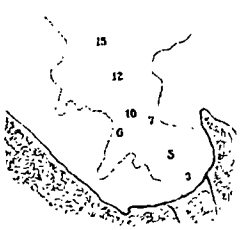
Coral reefs, although (1) *dependent on the configuration of the submarine lands for many of their features*, undergo various modifications of form, or condition, through the influence of extraneous causes, such as (2) *unequal exposure to the waves*; (3) *oceanic or local currents*; (4) *presence of fresh or impure waters*. In briefly treating of these topics, we may consider first, reefs around high islands, and afterwards, atoll reefs. The effect of the waves on different sides of reefs has already been considered, and we pass on, therefore, at once to the influence of oceanic or local currents, and fresh or impure waters.

I. BARRIER AND FRINGING REEFS.

The *existence of harbours* about coral-bound lands, and of entrances through reefs, is largely attributable to the action of tidal or local marine currents. The presence of fresh-water streams has some effect toward the same end, but much less than has been supposed. These causes are recognized by Mr. Darwin in nearly the same manner as here: yet the views

presented may be taken as those of an independent witness, as they were written out before the publication of his work.

There are usually strong tidal currents through the reef channels and openings. These currents are modified in character by the outline of the coast, and are strongest wherever there are coves or bays to receive the advancing tides. The harbour of Apia, on the north side of Upolu, affords a striking illustration of this general principle. The coast at this place has an indentation 2,000 yards wide and nearly 1,000 deep, as in the accompanying sketch, reduced from the chart by the Expedition. The reef extends from either side, or cape, a mile out to sea, leaving between an entrance for ships. The harbour averages ten feet in depth, and at the entrance is fifteen feet. In this harbour there is a remarkable out-current along the bottom, which, during gales, is so strong at certain states of the tide that a ship at anchor, although a wind may be blowing directly in the harbor, will often ride with a slack cable; and in more moderate weather the vessel may tail out *against* the wind. Thus when no current but one inward is perceived at the surface, there is an undercurrent acting against the keel and bottom of the vessel, which is of sufficient strength to counteract the influence of the winds on the rigging and hull. The cause of such a current is obvious. The sea is constantly pouring water over the reefs into the harbour, and the tides are periodically adding to the accumulation; the indented shores form a narrowing space where these waters tend to pile up: escape consequently takes place along the bottom by the harbour-entrance, this being the only means of exit. There are many such cases about all the islands. In a group like the Feejees, where a number of the islands are large and the reefs very extensive, the currents are still more remarkable, and they change in direction with the tides.



HARBOUR OF APIA, UPOLU.

"Through the channels and among the inner reefs of the Australian reef-region," says Jukes, "they run sometimes with an impetuous sweep in the same direction even for two or three days together, especially after great storms have driven large quantities of water into the space between the outer edge and the land."

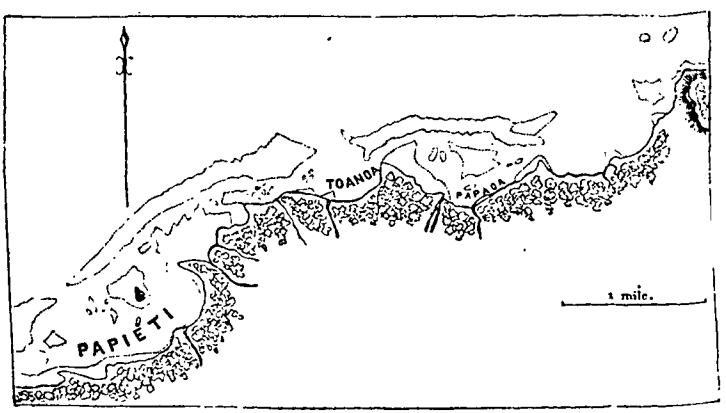
A current of the kind here represented will carry out much coral débris, and strew it along its course. The transported material will vary in amount from time to time, according to the force and direction of the current. It is therefore evident that the ground over which it runs must be wholly unfit for the growth of coral, since most zoöphytes are readily destroyed by depositions of earth or sand, and require, for most species, a firm basement. Or if the flow is very strong, it will scour out the channels and so keep them open. The existence of an opening through a reef may require, therefore, no other explanation; and it is obvious that harbours may generally be expected to exist wherever the character of the coast is such as to produce currents and give a fixed direction to them.

The currents, about the reef grounds west of the large Feejee Islands, aid in distributing the débris both of the land and the reefs. In some parts, the currents eddy and deposit their detritus; in others they sweep the bottom clean. Thus, under these varying conditions, there may be growing corals over the bottom in some places and not in others; and the reefs may be distributed in patches, when without such an influence we might expect a general continuity of coral reef over the whole reef-grounds.

The results from marine currents are often increased by waters from the island streams; for the coves, where harbours are most likely to be found, are also the embouchures of valleys and the streamlets they contain. The fresh waters poured in add to the amount of water, and increase the rapidity of the out-current. At Apia, Upolu, there is a stream thirty yards wide; and many other similar instances might be mentioned. These waters from the land bring down also much detritus, especially during freshets, and the depositions aid those from

marine currents in keeping the bottom clear of growing coral. These are the principal means by which fresh-water streams contribute toward determining the existence of harbours; for little is due to their freshening the salt waters of the sea.

The small influence of the last-mentioned cause—the one most commonly appealed to—will be obvious, when we consider the size of the streams of the Pacific islands, and the fact that fresh water is lighter than salt, and therefore, instead of sinking, flows on over its surface. The deepest rivers are seldom over six feet, even at their mouths; and three or



PART OF THE NORTH SHORE OF TAHITI.

four feet is a more usual depth. They will have little effect, therefore, on the sea water beneath this depth, for they cannot sink below it; and corals may consequently grow even in front of a river's mouth. Moreover the river water becomes mingled with the salt, and, in most cases, a short distance out, would not be unfit for some species of coral zoöphytes.

Fresh-water streams, acting in all the different modes pointed out, are of little importance in harbour-making about the islands of the Pacific. The harbours, with scarcely an exception, would have existed without them. They tend, however,

by the detritus which they deposit, to keep the bottom more free from growing patches of coral and consequently produce better anchorage ground; moreover, within the harbours they usually keep channels open through, or over, the shore reef sufficiently deep and wide for a boat to reach the land, and sometimes preserve a clean sand-beach throughout. That this is their principal effect will appear from a few facts.

The map of the reef of North Tahiti, between Papieti on the left, and the west cape of Matavai harbour, on the right, here reproduced, affords illustrations of this subject.

a. The harbour of Papieti is inclosed by a reef about three-fourths of a mile from the shore. The entrance through the reef is narrow, with a depth of eleven fathoms at centre, six to seven fathoms either side, and three to five close to the reef. This fine harbour receives an unimportant streamlet, while a much larger stream empties itself just to the east of the east cape, *opposite which the reef is close at hand and unbroken.*

b. Toanoa is the harbour next east of Papieti. The entrance is thirty-five fathoms deep at middle, and three and a half to five fathoms near the points of the reef. There is no fresh-water stream, except a trifling rivulet.

c. Papaoa is an open expanse of water, harbour-like in character, but is without any entrance; the reef is unbroken. Yet there are two streams emptying into it, one of which is of considerable size.

d. Off Matavai, the place next east, the reef is interrupted for about two miles. The harbour is formed by an extension of the reef off Point Venus, the east cape. There is no stream on the coast, opposite this interruption in the reef, except toward Point Venus, and at the present time the waters find their principal exit east of the Point, behind a large coral reef, but a quarter of a mile distant.

From such facts, it is evident that the growth of coral reefs is not much retarded about the Pacific Islands by fresh-water streams. We cannot be surprised at the little influence they appear to have exerted about Tahiti, when knowing that none of these so-called rivers are over three feet in depth; and the

most they can do is to produce a thin layer of brackish water over the sea within the channels.

e. The following figure of the harbour of Falifa, Upolu, represents another coral harbour, as surveyed by Lieutenant Emmons. At its head there is a stream twenty-five or thirty yards wide and three feet deep. Notwithstanding the unusual size of the river, the coral reef lies near its mouth, and projects some distance in front of it. Its surface is dead, but corals are growing upon its outer slope.

f. The harbour of Rewa, in the Feejees, may be again alluded to. The waters received by the bay amount to at least 500,000 cubic feet a minute. Yet there is an extensive reef inclosing the bay, lying but three miles from the shores, and with only two narrow openings for ships. The case is so remarkable that we can hardly account for the facts without supposing the river's mouth to have neared the reef by depositions of detritus since the inner parts of the reef were formed; and there is some evidence that this was the case, though to what distance we cannot definitely state. With this admission, the facts may still surprise us; yet they are explained on the principle that fresh water does not sink in the ocean, but is superficial, and runs on in a distinct channel; its effect is almost wholly through hydrostatic pressure, increasing the force of the underwater currents, and through their depositions of detritus. Besides these instances, there are many others in the Feejees, as will be observed on the chart at the end of this volume. Mokungai has a large harbour, without a stream of fresh water;—so also Vakea and Direction Island.



HARBOUR OF FALIFA.

The instances brought forward are a fair example of what is to be found throughout coral seas; and they establish, beyond dispute, that while much in harbour-making should be attributed to the transported sand or earth of marine and fresh-

water currents, in preventing the growth of coral, but little is due to the freshening influence of the streams of islands.

But while observing that currents have so decided an influence on the condition of harbours, we should remember another prevalent cause already remarked upon, which is perhaps more wide in its effects than those just considered. I refer to the features of the supporting land, or the character of soundings off a coast. We need not repeat here the facts, showing that many of the interruptions of reefs have thus arisen. The wide break off Matavai may be of this kind. The widening of the inner channel at Papieti, forming a space for a harbour, may be another example of it; for the reef here extends to a greater distance from the shores, as if because the waters shallowed outward more gradually off this part of the coast.

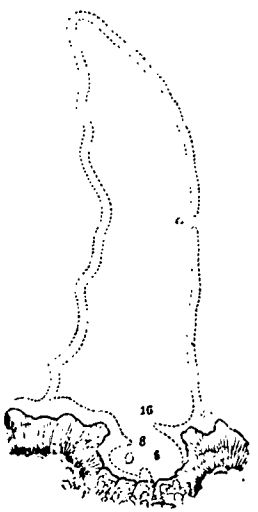
The same cause—the depth of soundings, on the principle that corals do not grow where the depth much exceeds a hundred feet—has more or less influence about all reefs in determining their configuration and the outlines of harbours. A remarkable instance of the latter is exemplified in the annexed chart of Whippey harbour, Viti Levu, reduced from the chart of the Wilkes Expedition to the scale of half an inch to the mile.

The existence of harbours should therefore be attributed, to a great extent, to the configuration of the submarine land; while currents give aid in preventing the closing of channels, and keeping open grounds for anchorage. This subject will be further illustrated in the following pages.

The permanency of coral harbours follows directly from the facts above presented. They are secure against any immediate obstruction from reefs. Any growing patches within them may still grow, and the margins of the inclosing reef may gradually extend and contract their limits; yet only at an extremely slow rate. Notwithstanding such changes, the channels will remain open, and large anchorage grounds clear, as long as the currents continue in action. Coral harbours are therefore nearly as secure from any new obstructions as those

of our continents. The growing of a reef in an adjoining part of the coast, may in some instances diminish or alter the currents, and thus prepare the way for more important changes in the harbour; but such effects need seldom be feared, and results from them would be appreciable only after long periods, since, even in the most favourable circumstances, the growth of reefs is very slow.

When channels have a bottom of growing coral, they form an exception to the above remark; for since the coral is acted upon by no cause sufficient to prevent its growth, the reef will continue to rise slowly toward the surface.



WHIPPEY HARBOUR, VITI LEVU.

Again, when the channels are more than twenty fathoms in depth, they have an additional security beyond that from currents, in the fact that corals will not grow at such a depth. The only possible way in which such channels could close, without first filling up by means of shore material, would be by the extension of the reefs from either side, till they bridge over the bottom below. But such an event is not likely to happen in any but narrow channels.

In recapitulation, the existence of passages through reefs, and the character of the coral harbours, may be attributed to the following causes :—

1. The configuration and character of the submarine land; —corals not growing where the depth exceeds certain limits, or where there is no firm rocky basement for the plantation.

2. The direction and force of marine currents, with their transported detritus;—these currents having their course largely modified, if not determined, as in other regions, by the features of the land, the form of the sea-bottom and the posi-

tions of the reefs, and being sometimes increased in force by the contributions of island streams, which add to the detritus and to the weight of accumulating waters.

3. Harbours which receive fresh-water streams, or submarine springs of fresh-water, are more apt to be clear from sunken patches; and the same causes keep open shallow passages to the shores, where there are shore reefs.

It should be remembered, that while the effects from fresh-water streams are so trifling around islands, they may be of very wide influence on the shores of the continents where the streams are large and deep, and transport much detritus. This point is illustrated further on.

II. ATOLL REEFS.

The remarks in the preceding pages respecting reefs around other lands apply equally to atoll reefs. There are usually currents flowing to leeward through the lagoon, and out, over, or through the leeward reef, the waves with the rising tide dashing over the windward side, and keeping up a large supply, which is greatly increased in times of storms; and this action tends to keep open a leeward channel for the passage of the water. This is the common explanation of the origin of the channels opening into lagoons. These currents are strongest when a large part of the windward reef is low, so as to permit the waves to break over it; and the coral débris they bear along will then be greatest. When a large part of the leeward reef is under water, or barely at the water's edge, the waters may escape over the whole, and on this account large reefs sometimes have no proper channels. When the land to windward becomes raised throughout above the sea, so as to form a continuous barrier which the waves cannot pass, the current is less perfectly sustained, since it is then dependent entirely upon the influx and efflux of the tides; and the leeward channels, in such a case, may gradually become closed.

The action of currents on atolls is, therefore, in every way identical with what has been explained. The absence of

coves of land to give force to the waters of currents, and to direct their course, and the absence also of fresh-water streams, are the only modifying causes not present. It is readily understood, therefore, why lagoon entrances are more likely to become filled up by growing coral, than the passages through barrier reefs.

III. RATE OF GROWTH OF REEFS.

The formation of a reef has been shown to be a very different process from the growth of a zoöphyte. Its rate of progress is a question to be settled by a consideration of many distinct causes, none of which have yet been properly measured.

a. The rapidity of the growth of zoöphytes is an element in this question of great importance, and one that should be determined by direct observation with respect to each of the species which contribute largely to reefs, both in the warmer and colder parts of coral-reef seas.

b. The character of the coral plantation under consideration should be carefully studied; for it is of the greatest consequence to know whether the clusters of zoöphytes are scattered tufts over a barren plain, or whether in crowded profusion. Compare the débris of vegetation on the semi-deserts of California with that of regions buried in foliage; equally various may be the rate of growth of coral rock in different places. An allowance should also be made for the shells and other reef relics. The amount of reef-rock formed in a given time cannot exceed, in cubic feet, the aggregate of corals and shells added by growth—that is, if there are no additions from other distant or neighbouring plantations.

c. It is also necessary to examine all conditions that are connected with, or can influence, the marine or tidal currents of the region—their strength, velocity, direction, where they eddy, and where not, whether they flow over reefs that may afford débris or not. All the débris of one plantation may sometimes be swept away by currents to contribute to other

patches, so that one will enlarge at the expense of others. Or currents may carry the detritus into the channels or deeper waters around a coral patch, and leave little to aid the plantation itself in its increase and consolidation.

d. The course and extent of fresh waters from the land, and their detritus, should be ascertained.

e. The strength and height of the tides, and general force of the ocean waves, will have some influence.

Owing to the action of these causes, barrier reefs enlarge and extend more rapidly than inner reefs. The former have the full action of the sea to aid them, and are farther removed from the deleterious influences which may affect the latter.

No results with reference to this question of the rate of progress in reefs were arrived at by the author in the course of his observations in the Pacific. The general opinion, that their progress is exceedingly slow, was fully sustained. The facts with regard to the growth of zoöphytes give some data.

Allowing that the large Madrepora of the wreck, mentioned on page 99, may grow three inches in height a year, and that other Madrepores increase in the same ratio, it is still not easy to deduce from it the rate of increase of the reef. In the first place, the whole Madrepore is growing over the sides of its branches, at the rate, if we may judge from the size of the trunk at base, of a tenth of an inch a year, thus increasing annually the diameter a fifth of an inch a year, which, in a large species, is a very great addition to the three inches per year at the extremities of the branches. Again, the branches of the large Madrepore of the wreck were widely spaced, those of *M. cervicornis* having intervals of from six to eighteen inches or more between the branches.

In fact it is impossible to make any exact estimate of the amount of increase without a knowledge of the weight of the part annually added. This ascertained, it would be easy to calculate how much the added coral would, if ground up, raise the area that is covered by the Madrepora. A rough estimate gives the author an average increase to this surface of a fourth of an inch a year. But this fourth must be much

reduced, if we would deduce the rate of growth of the reef; because a large part of the reef-grounds—that is, of the region of soundings receiving the coral débris—is bare of growing corals. This is the case with much the larger portion of all lagoons and channels among reefs, the bottoms of which, as already explained, are often sandy or muddy, and to a great extent so because too deep for living corals; and it is true even of the coral plantations, these including many and large barren areas. These unproductive portions of reef-grounds constitute ordinarily at least two-thirds of the whole; and making this allowance, the estimate of one-fourth of an inch a year would become one-twelfth of an inch.

Again, shells add considerably to the amount of calcareous material, perhaps one-sixth as much as the corals; but against this we may set off the porosity of the coral.

The rate of growth of the *Mæandrina divosa*, stated on page 98, would make the rate of increase in the reef very much less rapid. The specimen—the growth of fourteen years—weighs 24 oz. avoirdupois, and has an average diameter of 7 inches. This gives for the amount of calcareous material—the specific gravity being 2·523 (p. 75)—16·45 cubic inches; which is sufficient to raise a surface seven inches in diameter to a height of 0·428 inch; and consequently the average *yearly* increase would be about 1-33d of an inch. Allowing for two-thirds of the reef-ground being unproductive in corals, the rate of increase for the whole would become 1-100th of an inch. But supposing that shells add one-fourth as much as the corals to the reef material, the rate of increase would become about 1-80th of an inch per year.

The specimen of *Oculina diffusa*, referred to on page 98, weighs 44 ounces, which is five-sixths more than that of the Mæandrina, while the average diameter of the clump is the same. The average annual increase would consequently cover a circular area of seven inches diameter 1-18th of an inch deep. And making the same allowances as above, the rate for the year for the whole reef-grounds would be 1-44th of an inch. The specimen of Mæandrina mentioned by Major

Hunt, is not here made the basis of a calculation, because we have not the specimen for examination, and it is not certain that the diameter stated by him was not the horizontal diameter.

These estimates from the *Mæandrina clivosa* and *Oculina diffusa* have this great source of uncertainty, that the growth of the groups may not have been begun in the first year of the fourteen. Further, the corals obtained by Major Hunt near Fort Taylor, Key West, may not have been as favourably situated for growth as those of the outer margin of the reef. Again, we have made no allowance for the carbonate of lime that is supplied by the waters by way of cement, supposing that this must come originally, for the most part, from the reef itself. Besides, we have supposed, above, all the coral reef-rock to be solid, free from open spaces; and, further, it is not considered that much of it is a coral conglomerate, in which the fragments have their original porosity.

On the other side, we have not allowed for loss of débris from the reef grounds by transportation into the deep seas adjoining, believing the amount to be very small.

Whatever the uncertainties, it is evident that a reef increases its height or extent with extreme slowness. If the rate of upward progress is one-sixteenth of an inch a year, it would take for the addition of a single foot to its height, one hundred and ninety years, and for *five feet a thousand years.*

It is here to be considered, that the thickness of a growing reef could not exceed twenty fathoms (except by the few fee added through beach and wind-drift accumulations), even if existing for hundreds of thousands of years, unless there were at the same time a slowly progressing subsidence; so that if we know the possible rate of increase in a reef, we cannot infer from it the actual rate for any particular reef; for it may have been very much slower than that. Without a subsidence in progress, the reef would increase only its breadth.

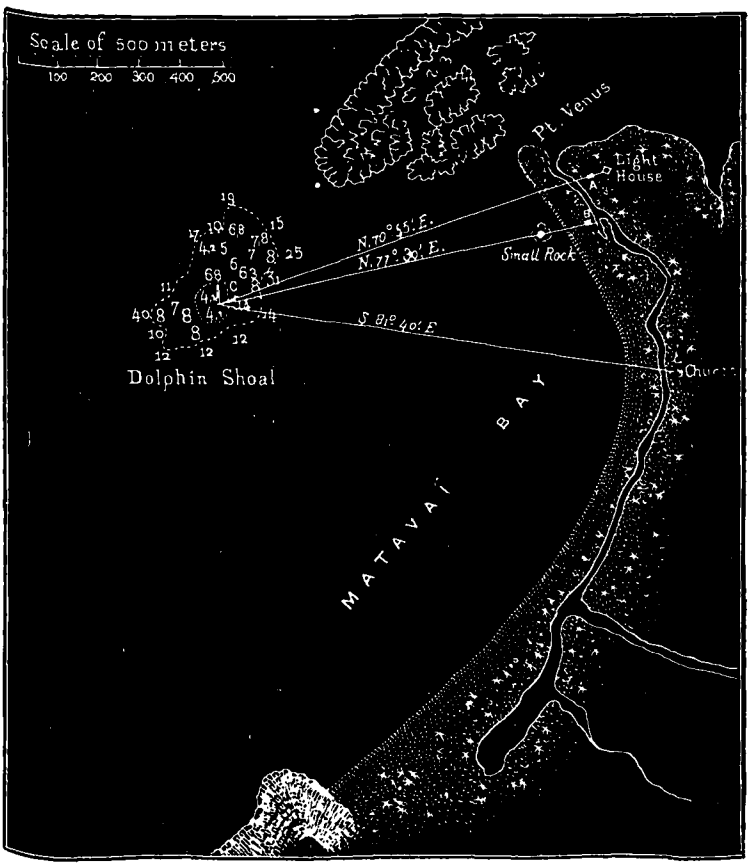
In order to obtain direct observations on the rate of increase of reefs, a slab of rock was planted, by the order of Captain Wilkes, on Point Venus, Tahiti, and by soundings, the depth

of Dolphin shoal, below the level of this slab, was carefully ascertained. By adopting this precaution, any error from change of level in the island was guarded against. The slab remains as a stationary mark for future voyagers to test the rate of increase of the shoal. Before, however, the results can be of any general value towards determining the average rate of growing reefs, it is still necessary that the growing condition of the reef should be ascertained, the species of corals growing upon it be identified, and the influence of the currents investigated which sweep in that direction out of Matavai bay.[1]

The depth to which the shells of Tridacnas lie imbedded in coral rock has been supposed to afford some data for estimating the growth of reefs. But Mr. Darwin rightly argues that these mollusks have the power of sinking themselves in the rock as they grow, by removing the lime about them. They

[1] Since the above was written, a memoir, by MM. Le Clere and de Bénazé, has appeared in Paris (1872), on their attempts to make use of the stone planted by Captain Wilkes in determining the rate of growth of the Dolphin Shoal. They made various measurements; but they observe that Wilkes does not state whether he measured from the top of a head of coral or from a solid bank on which the corals were growing, and further, that the use of an "excellent spirit level," from a stone of so little length is not sufficiently exact for correct results; and hence, were not able to draw any satisfactory conclusion from their results. Before leaving the region, they made the following arrangements with reference to future measurements. They planted two blocks of coral, cementing them below and nearly burying them in the soil, placing them 0·21 metres above the Wilkes stone which is between them; they then put a mark upon them on plates of metal, directed toward the place of observation on the shoal. A third stone was placed 40 metres from the south-west angle of the Point Venus lighthouse, in order to give a second observation on the position of the spot on which soundings were to be made. This spot was found to bear from the two new stones N. 77° 30′ E.; from the third stone N. 70° 55′ E.; from the bell of the new mission church S. 81° 40′ E. A horizontal line passing from the mark on the new stone is 7·460m above the madreporic heads. This observation they leave for comparison with future measurements. They farther made observations that satisfied them that Tahiti was not at present undergoing any general elevation. Two maps accompany the pamphlet; one is copied from Wilkes; the other (see opposite page) is from a chart by MM. Le Clerc and Minier, lieutenants of the vessel, and contains lines showing the position of the points referred to above.

occur in the dead rock—generally where there are no growing corals, except rarely some small tufts. If they indicate any-



thing, it must be the growth of the reef-rock, and not of the corals themselves. But the shore-platform where they are found is not increasing in height; its elevation above low-tide

being determined, as has been shown, by wave action (page 197). They resemble, in fact, other saxicavous mollusks, several species of which are found in the same seas, some buried in the solid masses of dead coral lying on the reef. The bed they excavate for themselves is usually so complete that only an inch or two in breadth of their ponderous shells are exposed to view. Without some means like this of securing their habitations these mollusks would be destroyed by the waves; a tuft of byssus, however strong, which answers for some small bivalves, would be an imperfect security against the force of the sea for shells weighing one to five hundred pounds.

IV. ORIGIN OF THE BARRIER CONDITION OF REEFS, AND OF THE ATOLL FORMS OF CORAL ISLANDS.

1. OLD VIEWS.

In the review of causes modifying the forms of reefs, no reason is assigned for the most peculiar, we may say the most surprising, of all their features—that they so frequently take a belt-like form, and inclose a wide lagoon; or, in other cases, range along at a distance of some miles, it may be, from the land they protect, with a deep sea separating them from the shores.

This peculiar character of the coral island was naturally the wonder of early voyagers, and the source of many speculations. The instinct of the polyp was made by some the subject of special admiration; for the "helpless animalcules" were supposed to have selected the very form best calculated to withstand the violence of the waves, and apparently with direct reference to the mighty forces which were to attack the rising battlements. They had thrown up a breastwork as a shelter to an extensive working ground under its lea, "where," as Flinders observes, "their infant colonies might be safely sent forth."

It has been a more popular theory that the coral structures were built upon the summits of volcanoes,—that the crater of the volcano corresponded to the lagoon, and the rim to the belt of land; that the entrance to the lagoon was over a break in the crater, a common result of an eruption. This view was apparently supported by the volcanic character of the high islands in the same seas. But since a more satisfactory explanation has been offered by Mr. Darwin, numerous objections to this hypothesis have become apparent, such as the following:—

a. The volcanic cones must either have been subaerial and then have afterward sunk beneath the waters, or else they were submarine from the first. In the former case the crater would have been destroyed, with rare exceptions, during the subsidence; and in the latter there is reason to believe that a distinct crater would seldom, if ever, be formed.

b. The hypothesis, moreover, requires that the ocean's bed should have been thickly planted with craters—seventy in a single archipelago,—and that they should have been of nearly the same elevation; for if more than twenty fathoms below the surface, corals could not grow upon them. But no records warrant the supposition that such a volcanic area ever existed. The volcanoes of the Andes differ from one to ten thousand feet in altitude, and scarcely two cones throughout the world are as nearly of the same height as here supposed. Mount Loa and Mount Kea, of Hawaii, present a remarkable instance of approximation, as they differ but two hundred feet; but the two sides of the crater of Mount Loa differ three hundred and fourteen feet in height. Mount Kea, though of volcanic character, has no large crater at top. Hualalai, the third mountain of Hawaii, is 4,000 feet lower than Mount Loa. The volcanic summit of East Maui is 10,000 feet high, and contains a large crater; but the wall of the crater on one side is 700 feet lower than the highest point of the mountain; and the bottom of the crater is 2,000 feet below the rim of the crater. Similar facts are presented by all volcanic regions.

c. It further requires that there should be craters over fifty

miles in diameter, and that twenty and thirty miles should be a common size. Facts give no support to such an assumption.

d. It supposes that the high islands of the Pacific, in the vicinity of the coral islands, abound in craters; while, on the contrary, there are none, so far as is known, in the Marquesas, Gambier, or Society Group, the three which lie nearest to the Paumotus. Even this supposition fails, therefore, of giving plausibility to the crater hypothesis.

Thus at variance with facts, the theory has lost favour, and it is no longer sustained even by those who were once its strongest advocates.

The question still recurs with regard to the basement of coral islands, and the origin of their lagoon character. Shall we suppose, with some writers, that these islands were planted upon submarine banks, within one hundred and fifty feet of the surface of the sea? As has been said, there is no authority for the supposition. We nowhere find regions over our continents with elevations so uniform in height; and submerged banks of this kind are of extremely rare occurrence. If such patches of submerged land existed, the lagoon structure would still be as inexplicable as ever; for the growing reefs of the Pacific show that corals may flourish alike over all parts of the bank, where not too deep. The zoöphyte can by no means be said to prefer the declivity to the central plateau of the submarine bank; on the contrary, the part nearest the surface below low-tide level, abounds in the largest species of corals.

II. ORIGIN OF CHANNELS WITHIN BARRIERS.

A study and comparison of the reefs of different kinds,—fringing, barrier and atoll,—throughout the oceans, is the only philosophical mode of arriving at any conclusion on this subject. This course Mr. Darwin has happily and successfully pursued, and has arrived, as we have reason to believe, at the true theory of barrier reefs and coral islands. It is satisfactory, because it is a simple generalization of facts. The explora-

tions of the author afforded him striking illustrations of its truth; and elucidate some points which were still deemed obscure, establishing the theory, as he believes, on a firm basis of evidence, and exhibiting its complete correspondence with observation.

The reader may turn again to the chart of the Feejee Group, and glance successively at the islands Goro, Angau, Nairai, Lakemba, Argo Reef, Exploring Isles, and Nanuku. It will be observed that in Goro, the reef closely encircles the land upon whose submarine shores it was built up. In the island next mentioned, the reef has the same character, but is more distant from the shores, forming what has been termed a barrier reef; the name implying a difference in position, but none in mode of formation. In the last of the islands enumerated, the barrier reef includes a large sea, and the island it incloses is but a rocky peak within this sea.

Can we account for this diversity in the position of barrier reefs, and in their extent as compared with the inclosed land? There is evidently one way, in accordance with Mr. Darwin's theory, in which these features might have been produced. If, for example, such an island as Angau were very gradually to subside, from some subterranean cause, two results would take place:—the land would slowly disappear, while the coral reef, ever in constant upward increase, as has been explained, might retain itself at the surface, if the rapidity of subsidence were not beyond a certain rate. This subsidence might go on till the last mountain peak remained alone above the waters. Shouid we not then have a Nanuku? Suppose the subsidence not to have proceeded to this extent, but to leave still a single ridge and a few isolated summits above the waves; would not its condition in this case be that of the Exploring Isles? On such a supposition, reefs of large size encircling a mere point of rock might be explained even to every feature. The subsidence of Goro, on the same principle, would produce an Angau, or, carried further, a Nanuku.

It may here be remarked, that the fact that changes of level over vast areas of the earth's surface have taken place is fully

proved, and accounts of some of them which are now in progress, as that of Sweden and that of Greenland, are to be found in any geological treatise.

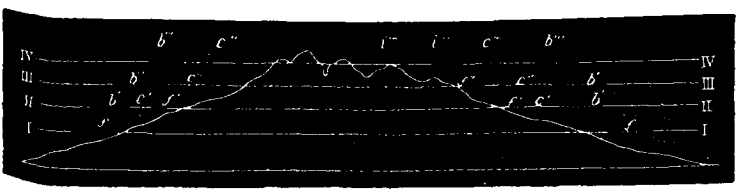
But it admits of direct demonstration that such a subsidence has actually taken place. It has been stated that the depth of the reef at different distances from the shore it encircles may generally be estimated from the slope of the shore. On this principle it has been shown on a former page (p. 125) that the thickness of the distant barrier reef cannot be less in some instances than a thousand feet; and in many cases it is probably much greater. Now as reef corals do not grow below eighteen or twenty fathoms, there is no way in which this thousand feet of reef could have been formed except by a gradual subsiding of the land upon which it stands. The large number of instances of distant barriers in the Pacific remove any doubt with regard to these conclusions. The map of the Feejees abounds in them through its eastern part, and we may infer with reason that over this extended area there has occurred, since the reefs began to form, a slowly progressing subsidence, like that which is now going on in Greenland.

Again, the island of Metia is 250 feet in height, full twice the coral-growing depth. At the island of Mangaia, in the Hervey group, the coral rock is raised 300 feet out of water. Such thick beds could not have been made by corals growing in depths not exceeding 120 feet without a sinking of many scores of feet during their progress.

The fact that subsidence has actually taken place during the formation of many reefs is therefore put beyond doubt. It must form a part of any true theory of reefs, whether it be the crater hypothesis, or the view here advocated. The latter has this advantage, that it explains all the facts, and requires no other element but this single one of subsidence. It rests on a simple fact and demands no hypothesis whatever.

The manner in which subsidence would operate is shown in the following sketches, representing ideal transverse sections of an island and its reefs. In the annexed figure, if I be the water line, the island, like Goro, has a simple fringing reef, *f*, *f*:

—it is a narrow platform of rock at the surface, dropping off at its edge to shallow depths, and then some distance out, declining more abruptly. Let the same island become submerged till II is the water line:—the reef extends itself upward, as submergence goes on, and may have the character at the surface represented by $b' f' b' f'$. There is here a fringing reef and also a barrier reef, with a narrow channel between, such as we have described as existing on the shores of Tahiti (see p. 206); b' is a section of the barrier, c' of the channel, and f' of the fringing reef. Suppose a farther submergence, till III is the water line: then the channel ($c'' c''$) within the barrier becomes quite broad, as in the island of Nairai or Angau; on one side (f''') the fringing reef remains, but on the other it has disappeared, owing perhaps, to some change of



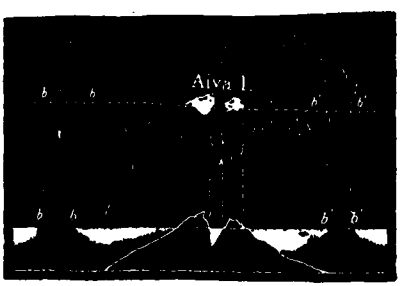
SECTION ILLUSTRATING THE ORIGIN OF THE BARRIER REEFS.

circumstance as regards currents, which retarded its growth, and prevented its keeping pace with the subsidence. With the water at IV, there are two islets of rock in a wide lagoon, along with other islets ($i''' i'''$) of reef over two peaks which have disappeared. The coral reef-rock by gradual growth has attained a great thickness, and envelops nearly the whole of the former land. Nanuku, the Argo Reef, and Exploring Isles are here exemplified, for the view is a good transverse section of either of them. $b''' b'''$ are sections of the distant inclosing barrier, and $c'' c''$, and other intermediate spots, of the water within.

The supposed similarity between these ideal sections and existing islands is fully sustained by actual comparison. The figure beyond is a map of the island of Aiva, in the Feejee Group. There are two peaks in the lagoon, precisely as above;

and although we have no soundings of the waters in and about it, nor sketches of peaks, facts observed elsewhere authorize in every essential point the transverse section here given, which resembles closely, as is apparent, the preceding. The section is made through the line *b b*, *b' b'*, of the map. It is unnecessary to add other illustrations. They may be made out from any of the eastern groups of the Feejees, the Gambier Group of the Paumotus, or Hogoleu in the Carolines. Wallis's Island is another example of islets of rock in a large lagoon inclosed by a distant barrier.

It has been asked, why the interior channels do not become filled by coral reef, as the island sinks, and thus a plane of coral



MAP, AND IDEAL SECTION, OF AIVA ISLAND.

result, instead of a narrow belt; and this has been urged against the theory. But it is a sufficient reply to such an argument to state the fact that the subsidence admits of no doubt, and that the islands referred to as exemplifications of it, present this very peculiarity. It should be received therefore, as a consequence of it, instead of an objection to the view, for it is the most common feature with all islands that have broad reef-grounds, or in other words, that show evidence of subsidence during the growth of the reefs. Broad channels, and even open seas within, as in Nanuku and the Exploring Isles, are therefore to be received as results of the subsidence, for which explanations should be sought.

These explanations are at hand, and accord so exactly with facts ascertained, that the existence of inner passages becomes a necessary feature of such islands. It has been shown that the ocean acts an important part in reef making;—that the outer reefs, exposed to its action and to its pure waters, grow more rapidly than those within, which are under the influence of marine and fresh-water currents and transported detritus. It is obvious, therefore, that the former may retain themselves at the surface, when through a too rapid subsidence the inner patches would disappear. Moreover, after the barrier is once begun it has growing corals on both its inner and outer margins, while a fringing reef grows only on one margin. Again, the detritus of the outer reefs is, to a great extent, thrown back upon itself by the sea without and the currents within, while the inner reefs contribute a large proportion of their material to the wide channels between them. These channels, it is true, are filled in part from the outer reefs, but proportionally less from them than from the inner. The extent of reef-grounds within a barrier, raised by accumulations at the same time with the reefs, is often fifty times greater than the area of the barrier itself. Owing to these causes the rate of growth of the barrier may be at least twice more rapid than that of the inner reefs. If the barrier increases one foot in height in a century, the inner reef, according to this supposition, would increase but half a foot; and any rate of subsidence between the two mentioned would sink the inner reefs more rapidly than they could grow, and cause them to disappear. There is therefore not only no objection to the theory from the existence of wide channels and open seas; on the contrary, their non-existence is incompatible with the mode of action going on. They afford the strongest support to the theory.

A wide, flat reef, continuous over extensive reef-grounds, could be formed only upon a nearly level bank, where there were consequently no hills to pour in detritus and otherwise retard growth over the interior portions; and even then it would be liable to be cut up by the action of currents, destroying growing corals over its interior parts.

From these considerations it is evident that a barrier reef indicates approximately the former limits of the land inclosed. The Exploring Isles (Feejee chart), instead of an area of *six* square miles, the whole extent of the existing land, once covered *three hundred* square miles; and the outline of the former land is indicated by the course of the inclosing reef. A still greater extent may be justly inferred. For a barrier, as subsidence goes on, gradually contracts its area, owing to the fact that the sea bears a great part of the material inward over the reefs; and, consequently, the declivity forming the outer limit of the sub-marine coral formation has a steep angle of inclination.

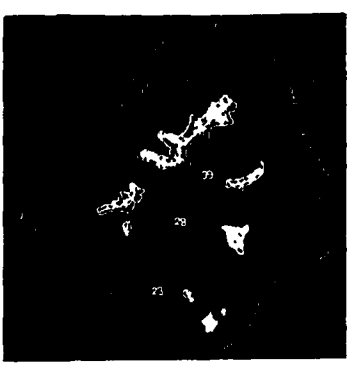
In the same manner it follows that the island Nanuku, instead of *one* square mile, extended once over *two hundred* square miles, or had two hundred times the present area of high land. Bacon's Isles once formed a large triangular island of equal extent, though now but two points of rock remain above the water.

The two large islands in the western part of the group, Vanua Levu and Viti Levu, have distant barriers on the western side. Off the north point of the former island, the reef begins to diverge from the coast, and stretches off from the shores till it is twenty and twenty-five miles distant; then, after a narrow interruption, without soundings, the Asaua islands commence in the same line, and sweep around to the reef which unites with the south side of Viti Levu; and, tracing the reef along the south and east shores, we find it at last nearly connecting with a reef extending southward from Vanua Levu. Thus these two large islands are nearly encircled in a single belt; and it would be doing no violence to principles or probabilities to suppose them once to have formed a single island, which subsidence has separated by inundating the low intermediate area. The singular reef of Whippey harbour, page 210, is fully explained by the hypothesis. We may thus not only trace out the general form of the land which once occupied this large area (at least 10,000 square miles), but may detect some of its prominent capes, as in Wakaia and Direction Island. The present area is not far from 4,500 square miles.

The whole Feejee Group, exclusive of coral islets, includes an area of about 5,500 square miles of dry land; while, at the period when the corals commenced to grow, there were, at least, as the facts show, 15,000 square miles of land, or nearly three times the present extent of habitable surface.

III. LAGOONS OF ATOLLS.

We pass from these remarks on the channels and seas within barrier reefs, to the consideration of the seas or lagoons of coral atolls. The inference has probably been already made by the reader, that the same subsidence which has produced



GAMBIER ISLANDS.

the distant barrier, if continued a step farther, would produce the lagoon island. Nanuku is actually a lagoon island, with a single mountain peak still visible; and Nuku Levu, north of it, is a lagoon island, with the last peak submerged. This mode of origin may evidently be true of all atolls; for, with the exception of the points of high land in the inner waters, there is no one essential character distinguishing many of the eastern Feejee Islands from the Carolines to the north. The Gambier Group, near the Paumotus, appears to have afforded

the philosophical mind of Mr. Darwin the first hint with regard to the origin of the atoll; the contrast, and, at the same time, the resemblance, were striking; the conclusion was natural and most happy. Captain Beechey, in his Voyage in the Pacific, implies this resemblance, when he says of the Gambier Group, which he surveyed, "It consists of five large islands and several small ones, *all situated in a lagoon formed by a reef of coral.*" Balbi, the geographer, as Mr. Darwin remarks (p. 41), describes those barrier reefs which encircle islands of moderate size by calling them atolls, with high lands rising from their central expanse.

As some interest is connected with the history of new principles, and the illustration afforded is highly satisfactory, we give here a sketch of the Gambier Group. The very features of the coast of the included islands,—the deep indentations,—are sufficient evidence of subsidence to one who has studied the character of the Pacific islands; for these indentations correspond to valleys or gorges formed by denudation during a long period while the island stood above the sea.

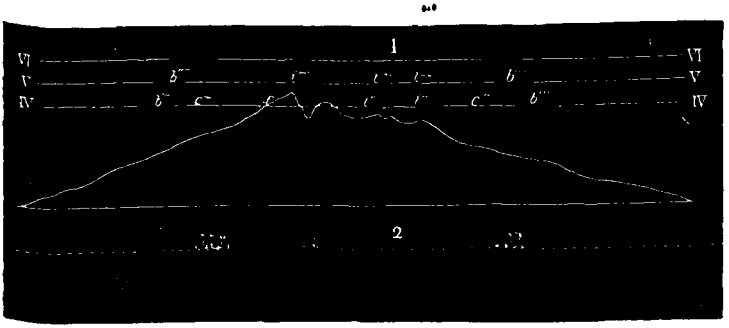
The manner in which a further subsidence results in producing the atoll is illustrated in the upper of the following figures. Viewing V as the water line, the land is entirely submerged; the barrier, b'''', b'''', then incloses a broad area of waters, or a *lagoon*, with a few island patches of reef over the peaks of the mountains. A continuation of the subsidence would probably sink beneath the waters some of the islets, because of their increasing in height less rapidly than the barrier: and this condition is represented along the upper line of the following figure, VI., subsidence having taken place to that level. The lagoon has all the characters of those of atoll reefs.

Should subsidence now cease, the reefs, no longer increasing in height, would go on to widen, and the accumulations produced by the sea would commence the formation of dry land, as exhibited in figure 2. Verdure may soon after appear, and the coral island will finally be completed. It is not impossible that dry land might form in certain favourable spots on the reef

while the subsidence was still in progress, if the sinking were not beyond a certain rate.

A cessation or diminution of subsidence, in the case of the barrier reef about a high island, might result in its becoming covered with verdure like the finished atoll.

All the features of atolls harmonize completely with this view of their origin. In form they are as various and irregular as the outlines of barrier reefs. Compare Angau of the Feejees, with Tari-tari of the Gilbert Group (p. 133); Nairai or Moala with Tarawa; Nanuku with Maiana or Apamama. The resemblance is close. In the same manner we might find the many forms of lagoon reefs represented among barrier reefs.



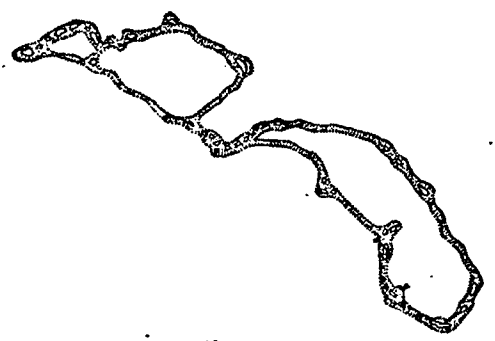
SECTION ILLUSTRATING THE ORIGIN OF ATOLLS.

We observe, also, that the configurations are such as would be derived from land of various shapes of outline, whether a narrow mountain ridge (as in Taputeouea, one of the Gilbert Islands), or wide areas of irregular slopes and mountain ranges. Among the groups of high islands, we observe that abrupt shores may occasion the absence of a reef on one side, as on Moala; and a like interruption is found among coral islands. Many of the passages through the reefs may be thus accounted for.

The fact that the submerged reef is often much prolonged from the capes or points of a coral island, accords well with

these views. These points or capes correspond to points in the original land, and often to the line of the prominent ridge; and it is well known that such ridge lines often extend a long distance to sea, with slight inclination compared with the slopes or declivities bounding the ridge on either side.

Coral islands or reefs often lie in chains like the peaks of a single mountain range:—for example, the sickle-shaped line of islets north of Nanuku. Tari-tari and Makin (Gilbert Group, see map, page 133) lie together, as if belonging to parts of one island. Menchicoff atoll, in the Caroline Archipelago, consists of three long loops or lagoon islands, united



MENCHICOFF ATOLL ($\frac{1}{10}$TH OF AN INCH TO A MILE).

by their extremities, and further subsidence might reduce it to three islands.

Darwin, in his account of the Maldives (op. cit., p. 37), points out indications of a breaking-up of a large atoll into several smaller. The land with many summits or ranges of heights may at first have had its single inclosing reef; but as it subsided, this reef, contracting upon itself, may have encircled separately the several ranges of which the island consisted, and thus several atoll reefs may have resulted in place of the large one; and, further, each peak may have finally become the basis of a separate lagoon island, under a certain rate of subsidence or variations in it, provided the outer reef were so

broken as to admit the influence of waves and winds. Some of the large atolls of the Maldives are properly atoll archipelagos.

The sizes of atolls offer no objection to these views, as they do not exceed those of many barrier reefs. Some of the larger Maldives, according to the crater theory, would require a crater forty to ninety miles in diameter, with a rim made up of subordinate craters. No hypothesis of such extravagance is necessary. The facts all fall in with known principles, and are illustrated by known and established truths, without hypotheses of any kind.

Reefs surrounded by shallow seas, gradually deepening outward, require no different principle for their explanation from reefs with abrupt depths around. The explanation of the peculiarities of the Bermudas, on page 188, can now be fully understood. If the original island had a high, bold mountain ridge along its south-eastern front, and low sloping land for the most part to the northward and westward, the result would have been what we find in fact. Previous to the elevation of 250 feet, indicated by the height of the hills, the shallow region on the north and west of the high land (the existing reef-region), must have been mostly bare of living corals, because lying at too great a depth. The elevation brought it near enough to the surface to again become a coral plantation. This *near enough*, in the Bermuda seas, means forty to fifty feet, for soundings show that wherever the depth is seven to eight fathoms the bottom is free from living corals. If the three great bays, A, B, C (see map of the Bermudas, p. 183), correspond to subordinate atolls, in a ring-group, then the subsiding peaks of the land became the centres of annular reefs; and the two eastern of the peaks were evidently quite close together.

It is of interest to follow still further the subsidence of a coral island, the earlier steps in which are illustrated in the preceding figures. One obvious result of its continuation is a gradual contraction of the lagoon and diminution of the size of the atoll, owing to the fact already noted, that the detritus

is mostly thrown inward by the sea. The lagoon will consequently become smaller and shallower, and the outline of the island in general more nearly circular. Finally, the reefs of the different sides may so far approximate by this process, that the lagoon is gradually obliterated, and the large atoll is thus reduced to a small level islet, with only traces of a former depression about the centre. Thus subsidence aids detritus accumulations in filling up the lagoon; and as filled lagoons are found only in the smallest islands, such as Swain's and Jarvis's, the two agencies have beyond doubt been generally united.

This subsidence, if more rapid than the increase of the coral reef, would become fatal to the atoll, by gradually sinking it beneath the sea. Such a fate has actually befallen two atoll-formed reefs of the Chagos Group, in the Indian Ocean (p. 156), as stated by Darwin; a third had only "two or three very small pieces of living reef rising to the surface," and the fourth has a portion nine miles long, dead and submerged. Darwin calls such reefs *dead reefs*. The southern Maldives have deeper lagoons than the northern, fifty or sixty fathoms being found in them. This fact indicates that subsidence was probably most extensive to the south, and perhaps also most rapid. The sinking of the Chagos Bank, which lies farther to the south, in nearly the same line, may therefore have had some connection with the subsidence of the Maldives.

In view of the facts which have been presented, it appears that each coral atoll once formed a fringing reef around a high island. The fringing reef, as the island subsided, became a barrier reef, which continued its growth while the land was slowly disappearing. The area of waters within finally contained the last sinking peak. Another period, and this had gone—the island had sunk, leaving only the barrier at the surface and an islet or two of coral in the inclosed lagoon. Thus the coral wreath thrown around the lofty island to beautify and protect becomes afterward its monument, and the only record of its past existence. The Paumotu Archipelago is a vast

island cemetery, where each atoll marks the site of a buried island. The whole Pacific is scattered over with these simple memorials, and they are the brightest spots in that desert of waters.

V. THE COMPLETED ATOLL.

The atoll, a quiet scene of grove and lake, is admirably set off by the contrasting ocean. Its placid beauty rises to grandeur when the storm rages, and the waves foam and roar about the outer reefs; for the child of the sea still rests quietly, in unheeding and dreamy content. This coral-made land is firm, because, as has been already explained, it is literally '*sea-born*, it having been built out of sea-products by the aid of the working ocean. And so with the groves: they were planted by the waves; and hence the species are those that can defy the encroaching waters, and meet the various conditions in which they are placed. The plants therefore take firm hold of the soil, and grow in all their natural strength and beauty.

Only an occasional coral island has a completely encircling grove, and is hence a model atoll. But the many in which a series of green islets surround the lagoon are often but little less attractive, especially when the several islets present varied groupings of palms and other foliage. To give perfection to the coral-island landscape there ought to be, here and there, beneath the trees, a pretty cottage or villa, and other marks of taste and intelligence; and now and then a barge should be seen gliding over the waters. As it is, the inhabitants are swarthy and nearly naked savages, having little about them that is pleasant to contemplate; and their canoes, with a clumsy outrigger to keep them right-side up, as well as their thatched huts, are as little in harmony as themselves with nature's grace and loveliness.

Where the islets of a coral reef are heaped up blocks of coral rock, blackened with lichens, and covered with barely enough of trailing plants and shrubs to make the surface green

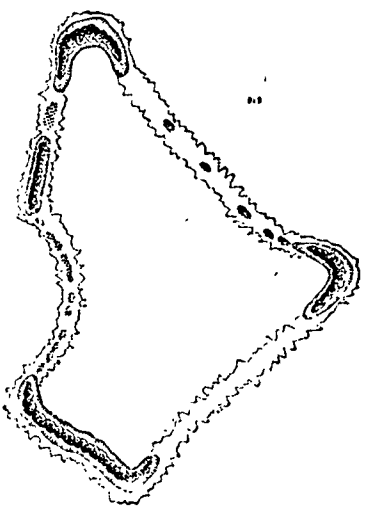
in the distant view, the traveller, on landing, would be greatly disappointed. But still there is enough that is strange and beautiful, both in the life of the land and sea, and in the history and features of the island, to give enjoyment for many a day.

The great obstacle to communication with a majority of atolls, especially the smaller, is the absence of an entrance to the lagoon, and hence of a good landing-place. In that case landing can be effected only on the leeward side, and in good weather; and best, when the tide is low. Even then, the sea often rolls in, so heavily, over the jagged margin of the reef, that it is necessary for the boat to take a chance to mount an in-going wave and ride upon it over the line of breakers to a stopping-place somewhere on the reef or shore-platform.

Less easy is the return through the breakers, especially if the sea has risen during the ramble ashore. The boat, in order to get off again, would naturally take one of the narrow channels or inlets indenting the margin of the reef. But, with the waves tumbling in one after another, roughly lifting and dropping it as they pass, and with barely room between the rocks for the oars to be used, there is a fair chance of its being dashed against the reefs to its destruction, or thrown broadside to the sea and swamped under a cataract of waters. If another boat with its crew were lying at the time off the reef, a line, carried to it through the surf by an expert swimmer, might prove a means of rescue:—and so, in 1840, we safely reached our ship. To those approaching such a shore in a boat, prudence would give the advice—first, drop, some distance outside of the breakers, a kedge or anchor, for aid both in landing on and leaving the reef. But the bottom of a coral island is often bad anchoring ground. And then, if the kedge thus planted holds firm, in spite of the jerking waves, well and good. If not——.

Bowditch or Fakaafo island is the easternmost of three small atolls, situated to the north of the Samoan or Navigator Group, near the parallels of $8\frac{1}{2}°$, $9°$, and $9\frac{1}{2}°$ S., and between the meridians of $171°$ and $172\frac{1}{2}°$ W., and has already been described

(p. 135). The grove of cocoanut-trees contains the sacred or public house of the island—a well-made structure measuring fifty feet by thirty-five in length and breadth, and twenty feet in height. In front of the building stands the deity of the place, consisting of a block of stone fourteen feet high, enveloped in mats; and also near by, a smaller idol, partially covered with matting. In the left corner there is a young cocoanut palm—usually a more beautiful object than the full-grown tree.



FAKAAFO, OR BOWDITCH ISLAND.

This island and the two others near it were among the few, perhaps the last, examples that remained until 1840, of Pacific lands never before visited by the white man. The people therefore were in that purely savage state which Captain Cook found almost universal through the ocean in the latter part of last century. A few words respecting our reception at this coral island may not, therefore, be an improper digression.

The islanders knew nothing of any other land or people:—an ignorance not surprising, since the lagoons of the group have no good entrances, and a nation cannot be great in navigation or discovery without harbours. As a consequence, our presence was to them like an apparition. The simple inhabitants took us for gods from the sun, and, as we landed, came with abundant gifts of such things as they had, to propitiate their celestial visitors. They no doubt imagined that our strange ship had sailed off from the sun when it touched the water at sunrise, or sunset, and any child among them could see that this was a reasonable supposition. The king, after embracing Captain Hudson, as the latter states in his Journal (Wilkes's Narrative), rubbed noses, pointed to the sun, howled, moaned, hugged him again and again, put a mat around his waist, securing it with a cord of human hair, and repeated the rubbing of noses and the howling; and the moment the captain attempted to leave his side, he set up again a most piteous howl, and repeated in a tremulous tone, "Nofo ki lalo, mataku au," "Sit down, I am afraid." While thus in fear of us, they showed a great desire that their dreaded visitors should depart; some pointed to the sun, and asked by their gestures about our coming thence, or hinted to us to be off again.

But with all their reverence toward their mysterious guests, they became after a while quite familiar, and took advantage of every opportunity to steal from us. Our botanist gave his collecting-box to one of them to hold, and, the moment his back was turned, off the native ran, and a hard chase was required to recover it—a most undignified run on the part of the celestial.

While the men wore the maro, the equivalent of tight-fitting breeches six inches or less in length, the women were attired in a simple bloomer costume, consisting solely of a petticoat or apron, twelve to eighteen inches long, made of a large number of slit cocoanut leaves, and kept well oiled. Besides this they had on, as ornaments, necklaces of shell or bone. The girls and boys were dressed *au naturel*, after the

style in the garden of Eden. These primitive fashions, however, are not peculiar to the group, being in vogue also in other parts of the Pacific.

As a set-off against the geographical ignorance of these islanders, we may state that Captain Hudson and the best map-makers of the age knew nothing of the existence of Bowditch Island until he discovered it; and from him comes the name it bears, given in honour of the celebrated author of "Bowditch's Navigator" as well as of the translation of Laplace's "Mécanique Céleste."

The Gilbert Group affords an example of a less isolated coral-island people. A beautiful view representing a part of the village of Utiroa, on Drummond's Island, is contained in the same volume of Wilkes's Narrative. The public house of the island is even larger than that on Bowditch Island, measuring one hundred and twenty feet in length, forty-five feet in width, and forty in height to the ridge-pole. This island, unlike the Duke of York's, was densely peopled, and, owing apparently to the scant supply of fish and vegetables thus occasioned, many of the natives were afflicted with leprosy, and also had bad teeth, both circumstances unusual for the Pacific. Lean in body and savage in look and gesture, they strangely contrasted with their fat, jolly kinsmen on some of the more northern islands of the same group. An old, fat chief who came from one of these islands to the ship's side in his canoe was actually too large to have reached the deck except by the use of a tackle. It was evident that infanticide—a necessity according to their system of political economy—was more thoroughly practised than on Drummond's Island, and that the population was thus kept from becoming uncomfortably numerous. The obesity was probably owing to their having nothing to do, and plenty, in the vegetable way, to eat; for these somewhat elevated equatorial islands, as elsewhere observed, are unusually productive for atolls,—just the place for a voluptuous barbarian.

The people on Drummond's Island were great thieves, and knew the pleasures of a cannibal feast. Without metals, or

any kind of hard stone, they make, out of the teeth of the sharks caught about the reefs, a sharp, jagged edging for long knives, swords, and spears; and the women, jealous of one another, sometimes, as Mr. Hale says, carry about with them for months a small weapon of shark's teeth concealed under their dress, watching for an opportunity to use it; and desperate fights sometimes take place. The same author mentions also some good points in them: observing that the women are, for the most part, better treated than is common among uncivilized people; that the men do the hard out-door work, while the women clear and weed the ground, and attend to the domestic duties that naturally fall to them. "Custom also requires that when a man meets a female he shall pay her the same mark of respect that is rendered to a chief, by turning aside to let her pass,"—a rule that probably does not always hold in practice. He adds: "The word *manda* signifies among the Gilbert Islanders a man thoroughly accomplished in all their knowledge and arts, and versed in every noble exercise; a good dancer, an able warrior, one who has seen life at home and abroad, and enjoyed its highest excitements and delights—in short, a complete man of the world. In their estimation this is the proudest character to which any person can attain; and such a one is fully prepared to enter, at his death, on the highest enjoyments of their elysium."

Thus much for the human productions of coral islands.

Although the vegetation of coral islands has the luxuriance that characterizes more favoured tropical lands, the number of species of land plants is small. When Gray's "Botany of the Paumotus" shall appear, it will contain descriptions of only twenty-eight or thirty species. The most common kinds are the following:—

Portulacca oleracea *L.* (lutea of *Solander*).
Triumfetta procumbens *Forst.*
Tournefortia argentea *L.*
Scævola Konigii *Vahl.*
Ipomæa longiflora *R. Br.*
Lepidium piscidium *Forst.*
Pemphis acidula *Forst.*
Pandanus odoratissimus *L. f.*
Pisonia grandis *Parkinson.*
Morinda citrifolia *L.*
Guettarda speciosa *L.*

Cassytha filiformis *L.*
Gouldia Romanzoffiensis *A. Gr.*
Euphorbia Chamissonis *Boiss.*
Boerhavia diffusa *L.*
Boerhavia hirsuta *Wild.*
Achyranthes canescens *R. Br.*
Heliotropium prostratum *R. Br.*
Nesogenes euphrasioides, *A. DC.*
Asplenium Nidus *L.*
A Polypodium, and a species of Grass.

Still, there is a better supply than might be supposed. For the cocoanut, in view of its uses, is a dozen trees in one. Its trunk furnishes timber for the houses of the natives, and the best of wood, on account of its weight and strength, for clubs and spears, weapons much in use, besides serving as ornamental side-arms. Its leaves supply material for thatching; for coarse matting to sit on, and beautiful fine mats for use in the way of occasional dress; also for the short aprons or petticoats of the women, above alluded to. The fruit, besides its delicately-flavoured hollow kernel, affords, by the grating of this kernel, a milky juice, that is richer than cream for purposes of native cookery, and which we explorers often used with satisfaction in coffee, cows being unknown in those regions; also, from each nut, a pint of the thinner "cocoanut milk," a more agreeable drink in the land of cocoanuts than in New York; also an abundant oil, much valued for sleeking down their naked bodies, and sometimes offered to a friendly visitor whom they would honour with a like anointing. Further, from the young fruit, three-fourths grown, comes a delightful beverage as brisk nearly as soda-water, besides a rich creamy pulp; both of these far better than the corresponding products of the ripe fruit. The husk is excellent for cordage, twine, thread, fishing-lines; and the smaller cord serves in place of nails for securing together the beams of their domestic and public buildings, and also for ornamenting the structure within, the cord being often wound with much taste and diversity of figures. The nut is, when opened, a ready-made drinking cup or cooking utensil. Finally, the developing bud, before blossoming, yields a large supply of sweet juice, from which molasses is sometimes made, and then, by fermentation, a spirituous liquor, called among the Gilbert Islanders by a name that sounded very much like toddy,

and possessing qualities that answer to the name; but this is procured at the expense of the fruit and the good of the tree, and also of the best interests of the natives.

It is doubted whether the ocean is ever successful in planting the cocoanut on coral islands. The nut seems to be well fitted for marine transportation, through its thick husk, which serves both as a float and a protection; but there is no known evidence that any island never inhabited has been found supplied with cocoanut-trees. The possibility of a successful planting by the waves cannot be denied; but there are so many chances that the floating nut will be kept too long in the water, or be thrown where it cannot germinate, that the probability of a transplanting is exceedingly small. This palm —the *Cocos nucifera* of the botanists—is not included in the list of native coral island species on page 238.

Another tree, peculiarly fitted for the region, is the Pandanus or *Screw-pine*—well named as far as the syllable *screw* goes, but having nothing of a *pine* in its habit. Its long, sword-like leaves, of the shape and size of those of a large Iris, are set spirally on the few awkward branches toward the extremity of each, and make a tree strikingly tropical in character. It grows sometimes to a height of thirty feet. It is well fitted for the poor and shallow soil of a coral island; for as it enlarges and spreads its branches, one prop after another grows out from the trunk and plants itself in the ground; and by this means its base is widened, and the growing tree supported. The fruit, a large ovoidal mass made up of oblong dry seed, diverging from a centre, each near two cubic inches in size, affords a sweetish husky article of food, which, though little better than prepared corn-stalks, admits of being stored away for use when other things fail; and at the Gilbert Islands, and others in that part of the ocean, is so employed.

The Pisonia is another of the forest trees, and is one of handsome foliage and large and beautiful flowers, sometimes attaining a height of forty feet, and the trunk twenty in girth.

Among the species that are earliest in taking root in the

emerging coral débris over the reef, there are the Portulaccæ (species of purslane); the *Triumphetta procumbens*, a creeping yellow-flowering plant of the Tilia family; the *Tournefortia sericea*, a low, hoary shrub, of the family Boraginaceæ, and *Scævola Konigii*, a sub-fleshy seashore plant.

On Rose Island, just east of the Navigator Group, Dr. C. Pickering, of the Wilkes Exploring Expedition, found only a species of Pisonia and of Portulacca. This is a small atoll, under water at high-tide, excepting two banks, one of which is covered with trees.

In the Marshall Group, on the contrary, where the vegetation is more varied, and the islands have probably undergone some elevation since they were made, Chamisso observed fifty-two species of land-plants, and in a few instances the banana, taro, and bread-fruit were cultivated. At the elevated coral island, Metia, north of Tahiti (p. 157), 250 feet above the sea, sugar-cane and bread-fruit, and many plants of the Society Group, occur.

Water is to be found commonly in sufficient quantities for the use of the natives, although the land is so low and flat. They dig wells five to ten feet deep in any part of the dry islets, and generally obtain a constant supply. These wells are sometimes fenced around with special care; and the houses of the villagers, as at Fakaafo, are often clustered about them. On Aratica (Carlshoff) there is a watering place 50 feet in diameter, from which vessels of the Wilkes Exploring Expedition obtained 390 gallons. The Gilbert Islands are generally provided with a supply sufficient for bathing, and each native takes his morning bath in fresh water, which is esteemed by them a great luxury. On Tari-tari (of the Gilbert Group, p. 133), as Mr. Horatio Hale, philologist of the same expedition, was informed by a Scotch sailor by the name of Grey, taken from the island, there is a trench or canal several miles long, and two feet deep. They have *taro* plantations (which is possible only where there is a large supply of water), and besides some bread-fruit. He spoke of the taro as growing to a very large size, and as being

in great abundance; it was planted along each side of the pond. Grey added further, that ten ships of the line might water there, though the place was not reached without some difficulty. There were fish in the pond, which had been put in while young. The bottom was adhesive, like clay. These islands have been elevated a little, but are not over fifteen feet above the sea.

Kotzebue observes, that "in the inner part of Otdia (one of the Marshall Islands), there is a lake of sweet water; and in Tabual, of the Group Aur, a marshy ground exists. There is no want of fresh water in the larger islands; it rises in abundance in the pits dug for the purpose."—*Voyage*, London, 1821, iii. 145.

The island of Quiros, or Gente-Hermosa, has, according to S. J. Whitnell, a *fresh-water* lagoon, only slightly brackish, about three miles in diameter. He states that the connection between the lagoon and the sea must have been closed at a comparatively recent date; its level is unaffected by the tides. There is a fresh-water lagoon also, according to the same authority, in the neighbouring island of Lakena.

The only source of this water is the rains, which, percolating through the loose sands, settle upon the hardened coral rock that forms the basis of the island. As the soil is white, or nearly so, it receives heat but slowly, and there is consequently but little evaporation of the water that is once absorbed.

Water is sometimes obtained by making a large cavity in the body of a cocoanut tree, two feet or so from the ground. At the Duke of York's Island, and probably also at the adjacent Bowditch Island, this method is put in practice; the cavities hold five or six gallons of water.

The tropical birds of the islands are often more in keeping with the beautiful scenery about them than the savage inhabitants. On one atoll—Honden Island, of the Paumotus, where no natives had ever dwelt—the birds were so innocent of fear, that we took them from the trees as we would fruit, and many a songster lost a tail-feather, as it sat perched on a branch,

apparently unconscious that the world contained an enemy. J. D. Hague gives an account of the birds of Jarvis's and some other uninhabited islands in the equatorial Pacific, in which it appears that, after all, there is evil doing even among tropical birds. He gives the following facts:—

"From fifteen to twenty varieties of birds may be distinguished among those frequenting the islands, of which the principal are the Gannets and Boobies, Frigate Birds, Tropic Birds, Tern, Noddies, Petrels, and some game birds, as the Curlew, Snipe, and Plover. Of Terns there are several species, the most numerously represented of which is what I believe to be the *Sterna hirundo*. These frequent the island twice in the year for the purpose of breeding. They rest on the ground, making no nests, but selecting tufts of grass, where such may be found, under which to lay their eggs. I have seen acres of ground thus thickly covered by these birds, whose numbers might be told by millions. Between the breeding seasons they diminish considerably in numbers, though they never entirely desert the island. They are expert fishers, and venture far out to sea in quest of prey. The Noddies (*Sterna stolida*) are also very numerous. They are black birds, somewhat larger than pigeons, with much longer wings, and are very simple and stupid. They burrow holes in the guano, in which they live and raise their young, generally inhabiting that part of the deposit which is shallowest and driest. Their numbers seem to be about the same throughout the year. The Gannet and Booby, two closely allied species (of the genus Sula), are represented by two or three varieties. They are large birds, and great devourers of fish, which they take very expertly, not only catching those that leap out of the water, but diving beneath the surface for them. They are very awkward and unwieldy on land, and may be easily overtaken and captured, if indeed they attempt to escape at all on the approach of man. They rest on the trees wherever there is opportunity, but in these islands they collect in great groups on the ground, where they lay their eggs and raise their young. One variety, not very

numerous, has the habit of building up a pile of twigs and sticks, twenty or thirty inches in height, particularly on Howlands, where more material of that sort is at hand, on which they make their nest. When frightened, these birds disgorge the contents of their stomachs, the capacity of which is sometimes very astonishing. They are gross feeders, and I have often seen one disgorge three or four large flying-fish fifteen or eighteen inches in length.'

"The Frigate Bird (*Tachypetes aquilus*) I have already alluded to. It is a large, rapacious bird, the tyrant of the feathered community. It lives almost entirely by piracy, forcing other birds to contribute to its support. These frigate birds hover over the island constantly, lying in wait for fishing birds returning from the sea, to whom they give chase, and the pursued bird escapes only by disgorging its prey, which the pursuer very adroitly catches in the air. They also prey upon flying-fish and others that leap from sea to sea, but never dive for fish, and rarely even approach the water.

"The above are the kinds of birds most numerously represented, and to which we owe the existing deposits of guano. Besides these are the Tropic Birds, which are found in considerable numbers on Howland's Island, but seldom on Jervis's or Baker's. They prefer the former, because there are large blocks or fragments of beach rock scattered over the island's surface, under which they burrow out nests for themselves. A service is sometimes required of this bird, which may, perhaps, be worthy of notice. A setting bird was taken from her nest and carried to sea by a vessel just leaving the island. On the second day, at sea, a rag, on which was written a message, was attached to the bird's feet, who returned to the nest, bringing with it the intelligence of the departed vessel. This experiment succeeded so well that, subsequently, these birds were carried from Howland's to Baker's Island (forty miles distant), and, on being liberated there, one after the other, as occasion demanded, brought back messages, proving themselves useful in the absence of other means of communication. The game birds, snipe, plover, and curlew, frequent the islands

in the fall and winter, but I never found any evidence of their breeding there. They do not leave the island in quest of prey, but may be seen at low-tide picking up their food on the reef, which is then almost dry.

"Some of the social habits of these birds are worthy of remark. The gannets and boobies usually crowd together in a very exclusive manner. The frigate birds likewise keep themselves distinct from other kinds. The tern appropriate to themselves a certain portion of the island; each family collects in its accustomed roosting place, but all in peace and harmony. The feud between the fishing birds and their oppressors, the frigate birds, is only active in the air; if the gannet or booby can but reach the land and plant its feet on the ground, the pursuer gives up the chase immediately."

The extensive reefs about coral islands, as already stated, abound in fish, which are easily captured, and the natives, with wooden hooks, often bring in larger kinds from the deep waters. From such resources a population of 7,000 persons is supported on the single island of Taputeuea, whose whole habitable area does not exceed six square miles.

There are also shell-fish of edible kinds, and others that are the source of considerable activity in pearl-fishing.

An occasional log drifts to the shores, and at some of the more isolated atolls, where the natives are ignorant of any land but the spot they inhabit, they are deemed direct gifts from a propitiated deity. These drift-logs were noticed by Kotzebue at the Marshall Islands, and he remarked also that they often brought stones in their roots. Similar facts have been observed at the Gilbert Group, and also at Enderbury's Island, and many other coral islands in the Pacific. The stones at the Gilbert Islands, as far as could be learned, are generally basaltic or volcanic, and they are highly valued among the natives for whetstones, pestles, and hatchets. The logs are claimed by the chiefs for canoes. Some of the logs seen by the author, like those at Enderbury's Island, were forty feet or more long. Several large masses of compact cellular lava occur on Rose

Island, a few degrees east of the Navigator Group: they were lying two hundred yards inside of the line of breakers. The island is uninhabited, and the origin of the stones is doubtful; they may have been brought there by roots of trees, or perhaps by some canoe.

Fragments of pumice and resin are transported by the waves to many of the islands in the Central Pacific. We were informed at the Gilbert Islands that the pumice was gathered from the shores by women and pounded up to fertilize the soil of their taro patches; and that it is common for a woman to pick up a peck a day.

Where this pumice comes from is not ascertained. It is probably drifted from the westward, and perhaps from volcanic islands of the Ladrones or Philippines. In addition, volcanic ashes are sometimes distributed over these islands, through the atmosphere. In this manner the soil of the Tonga Islands has been improved, and in some places it has even received a reddish colour. This group has its own active volcano to supply the ashes, and the volcanic group of the new Hebrides is not far distant to the south-west.

Notwithstanding all the products and all the attractions of a coral island, even in its best condition it is but a miserable place for human development, physical, mental or moral. There is poetry in every feature, but the natives find this a poor substitute for the bread-fruit and yams of more favoured lands. The cocoanut and pandanus are, in general, the only products of the vegetable kingdom afforded for their sustenance, and fish, shell-fish, and crabs from the reefs their only animal food. Scanty too is the supply; and infanticide is resorted to in self-defence, where but a few years would otherwise overstock the half a dozen square miles of which their little world consists—a world without rivers, without hills, in the midst of salt water, with the most elevated point but ten to twenty feet above high tide, and no part more than three hundred yards from the ocean.

In the more isolated coral islands, the language of the natives indicates their poverty as well as the limited productions and unvarying features of the land. All words like those for

mountain, hill, river, and many of the implements of their ancestors, as well as the trees and other vegetation of the land from which they are derived, are lost to them; and as words are but signs for ideas, they have fallen off in general intelligence. It would be an interesting inquiry for the philosopher, to what extent a race of men placed in such circumstances is capable of mental improvement. Perhaps the query might be best answered by another, How many of the various arts of civilized life could exist in a land where shells are the only cutting instruments,—the plants of the land in all but twenty-nine in number,—minerals but one,—quadrupeds none, with the exception of foreign rats or mice, — fresh-water barely enough for household purposes,—no streams, nor mountains, nor hills? How much of the poetry or literature of Europe would be intelligible to persons whose ideas had expanded only to the limits of a coral island; who had never conceived of a surface of land above half a mile in breadth,—of a slope higher than a beach,—of a change of seasons beyond a variation in the prevalence of rains? What elevation in morals should be expected upon a contracted islet, so readily overpeopled that threatened starvation drives to infanticide, and tends to cultivate the extremest selfishness? Assuredly, there is not a more unfavourable spot for moral or intellectual progress in the wide world than the coral island.

Still, if well supplied with foreign stores, including a good stock of ice, they might become, were they more accessible, a pleasant temporary resort for tired workers from civilized lands, who wish quiet, perpetual summer air, salt-water bathing, and boating or yachting; and especially for those who could draw inspiration from the mingled beauties of grove, lake, ocean, and coral meads and grottoes, where

> "————Life in rare and beautiful forms
> Is sporting amid the bowers of stone."

But after all, the dry land of an atoll is so limited, its features so tame, its supply of fresh water so small, and of salt water so large, that whoever should build his cottage on one of them

would probably be glad, after a short experience, to transfer it to an island of larger dimensions, like Tahiti or Upolu, one more varied in surface and productions; that has its mountains and precipices; its gorges and open valleys; leaping torrents not less than surging billows; and forests spreading up the declivities, as well as groves of palms and corals by the shores.

The mineral alluded to above as the one mineral product of atolls is calcite, or carbonate of lime, the material of the coral rock; and this is the only kind on the great majority of them.

But on some of the smaller islands, in the drier equatorial part of the ocean, there are, in addition to this, and the stones brought by logs with the floating pumice, beds of gypsum which have been made through the evaporation of sea-water (which holds it in solution) in the gradually drying lagoon basins; and also large deposits of guano from the multitudes of sea birds that occupy them. Such are Jarvis's, Baker's, Howland's, Malden's, McKean's, Birnie's, Phœnix's, Enderbury's, and probably other islands in the dry central equatorial Pacific. As these deposits are connected with the completion of the coral island, and its accompanying reduction in size, and illustrate one of the ways by which new minerals are added to a destitute land, a few facts are here cited from an article in the *American Journal of Science*, volume xxxiv. (1862), by J. D. Hague, who resided for several months on the islands he describes.

Baker's Island is situated in lat. 0° 13′ north, and long. 176° 22′ west from Greenwich, and excepting Howland's Island, forty miles distant, is very remote from any other land. It is about one mile long and two-thirds of a mile wide. The surface is nearly level; the highest point is twenty-two feet above the level of the sea, showing some evidence of elevation.

Above the crown of the beach there is a sandy ridge which encircles the guano deposit. This marginal ridge is about one hundred feet wide on the lee side of the island, and is there

composed of fine sand and small fragments of corals and shells mixed with considerable guano; on the eastern or windward side it is much wider, and formed of coarser fragments of corals and shells, which, in their arrangement, present the appearance of successive beach formations. Encircled by this ridge lies the guano deposit, occupying the central and greater part of the island. The surface of this deposit is nearly even, but the hard coral bottom which forms its bed has a gradual slope from the borders toward the centre, or, perhaps more properly, from north-west to south-east, giving the guano a variable depth from six inches at the edges to several feet at the deepest part.

Howland's Island is situated in lat. 0° 51′ north, and 176° 32′ west from Greenwich. It is about a mile and a half long by half a mile wide, containing above the crown of the beach an area of some 400 acres. The highest point is seventeen feet above the reef, and ten or twelve feet above the level of high tide. The general features of the island resemble those of Baker's. Its surface, at least on the western side, is somewhat depressed, and much of it is covered by a growth of purslane, grass, and other vegetation, like that on Baker's Island, but considerably more abundant. Near the centre of the island there are one or two thickets of leafless trees or brushwood, standing eight or ten feet high, and occupying an area of several acres. The tops of these trees, in which the birds roost, are apparently quite dead, but the lower parts, near the roots, show signs of life after every rain. The windward side of the island is formed by a succession of ridges composed of coral débris with some sand and shells, running parallel to the eastern beach, each one of which may, at earlier stages of the island's growth, have successively formed the weather shore. Occasionally among these ridges a sandy bed is met with, in which some little guano is mixed. On the lee side there is also a sandy margin of considerable width. Bits of pumice and pieces of driftwood are scattered all over the island's surface.

The main deposit of guano occupies the middle part of the

island, and stretches, with some interruptions of intervening sand, nearly from the north to the south end. Its surface is even, and in many places covered by a thick growth of purslane, whose thread-like roots abound in the guano where it grows. The deposit rests on a hard coral bottom, and varies in depth from six inches to four feet. The fact already observed at Baker's, that vegetation flourishes most where the guano is shallow, is also quite apparent here, and the consequent characteristic difference between the guano of the deep and shallow parts is distinctly marked.

Some interesting pseudomorphs occur buried in the guano of this island. Coral fragments of various species were found that had long been covered up under the deposit, and in some of which the carbonic acid had been almost entirely replaced by phosphoric acid. In such I have found seventy per cent. of phosphate of lime. In many others the change was only partial, and, on breaking some of these, in the centre was usually found a nucleus or *core* of coral, still retaining its original hardness and composition, while the external parts had been changed from carbonate to phosphate, which, though soft and friable, still preserved the structure and appearance of the coral.

Jarvis's Island is situated in lat. 0° 22′ south, and long. 159° 58′ west, from Greenwich. It is nearly two miles long by one mile wide, trending east and west, and containing about 1,000 acres. Like Baker's and Howland's, it has the general features of a coral island, but it differs from them essentially in the fact that it once contained a lagoon which has gradually been filled up with sand and detritus, while the whole island has undergone some elevation. It therefore presents a basin-like form, the surface being depressed from the outer edge toward the centre. It is encircled by a fringing reef, or shore platform, about 300 feet wide; from this a gradually sloping beach recedes, the crown of which is from eighteen to twenty-eight feet high, forming a ridge or border, of varying width, which surrounds the island like a wall, from the in-shore edge of which the surface of the island is gently depressed.

Within this depression there are other ridges, parallel to the outer one, and old beach-lines and water-marks, the remaining traces of the waters of the lagoon, marking its gradual decrease and final disappearance.

This flat depressed surface in the centre of the island is about seven or eight feet above the level of the sea. It bears but little vegetation, consisting of long, coarse grass, Mesembryanthemum and Portulacca, and that is near the outer edges of the island, where the surface is formed of coral sand mixed with more or less guano. In the central and lower parts the surface is composed of sulphate of lime (gypsum), and it is on this foundation that the principal deposit of guano rests.

In examining the foundation of the guano deposit on Baker's or Howland's Island, by sinking a shaft vertically, the hard conglomerate reef-rock is found directly underlying the guano. Resting on this foundation the guano has undergone only such changes as the climate has produced. On Jarvis's Island, however, after sinking through the guano, one first meets with a stratum of sulphate of lime (sometimes compact and crystalline, sometimes soft and amorphous), frequently two feet thick, beneath which are successive strata of coral sand and shells, deposited one above the other in the gradual process by which the lagoon was filled up. These horizontal strata were penetrated to a depth of about twenty feet. They were composed chiefly of fine and coarse sand with an occasional stratum of coral fragments and shells.

Of the origin of this sulphate of lime there can hardly be any doubt. As the lagoon was nearly filled up, while, by the gradual elevation of the island, the communication between the outer ocean and the inner lake was constantly becoming less easy, large quantities of sea-water must have been evaporated in the basin. By this means deposits would be formed containing common salt, gypsum, and other salts found in the waters of the ocean. From these the more soluble parts would gradually be washed out again by the occasional rains, leaving the less soluble sulphate of lime as we find it here.

Some additional light is thrown on this matter by the

different parts of the surface, which, though nearly flat, show some slight variety of level. The higher parts, particularly around the outer edges, are composed chiefly of coral sand, either mixed with or underlying guano. Nearer the centre is a large tract, rather more depressed, forming a shallow basin, in which the bulk of the sea-water must have been evaporated, and whose surface (now partly covered with guano) is a bed of sulphate of lime, while, further, there is a still lower point, the least elevated of the whole, where the lagoon waters were without doubt most recently concentrated. This latter locality is a crescent-shaped bed, about 600 feet long by 200 or 300 feet wide, having a surface very slightly depressed from the outer edge toward the middle. Around the borders are incrustations of crystallized gypsum and common salt, ripple-marks, and similar evidences of the gradually disappearing lake. The whole is composed of a crystalline deposit of sulphate of lime, which, around the borders, as already observed, is mixed with some common salt, while near the centre, where rain-water sometimes collects after a heavy shower, the salt is almost entirely washed out, leaving the gypsum by itself. It is closely, but not hard, packed, and is still very wet. By digging 18 or 24 inches down, salt-water may generally be found.

These facts help us to understand the varying conditions in which we now find the guano beds. The most important part, and that from which the importations have thus far come, rests on a bed of sulphate of lime, of an earlier but similar origin to that just described above; part rests on a coral formation; while still another part, covering a large tract, has been by the action of water mixed with coral mud.

The first-named deposit, lying on the sulphate of lime bed, has a peculiar character. It is covered by, or consists of, a hard crust, that is from one-fourth of an inch to an inch and a half in thickness, beneath which lies a stratum of guano varying in depth from one inch to a foot. In many places, where the guano was originally shallow, the whole is taken up and formed into the hard crust which then lies immediately on the sulphate. This crust, when pure, is snow-white, with an

appearance somewhat resembling porcelain, but is usually coloured more or less by organic matter. Generally it is very hard, and strongly cohesive, though sometimes friable, and it lies unevenly on the surface in rough fragments that are warped and curved by the heat of the sun. It consists chiefly of phosphoric acid and lime, but, owing to the variable amount of sulphate of lime, with which it is mechanically mixed, there is a lack of uniformity in different samples. Hence the percentage of phosphoric acid varies from over 50 per cent. to less than 30 per cent.

The gypsum or sulphate of lime is usually soft and amorphous, sometimes crystalline, and, at a depth of eighteen inches or two feet, occurs in hard, compact, crystalline beds. It is of a light snuff colour, and, where it underlies guano, is mixed with considerable phosphate of lime, which has been washed down from the surface. Similar deposits of sulphate of lime occur on many other elevated lagoon islands of the Pacific.

Starbuck's, Starve or Hero Island, is an elevated atoll, and is worthy of mention, because like Jarvis's, McKean's, and other islands of similar structure, it contains a large deposit of gypsum. Its supposed guano I have found to consist of the hydrated sulphate of lime, containing about twelve per cent. of phosphate of lime, and coloured by a little organic matter. So far as my observation extends, all elevated lagoons have similar deposits of gypsum.

As regards the distribution of these phosphatic guano deposits, I believe them, in this region of the Pacific, to be confined to latitudes very near the equator, where rain is comparatively of rare occurrence. In latitudes more remote from the equator than 4° or 5°, heavy rains are frequent, and this circumstance is not only directly unfavourable to the formation of guano deposits, but it encourages vegetation; and when an island is covered with trees and bushes, the birds preferring to roost in them, there is no opportunity for the accumulation of guano deposits.

An article in the same Journal (vol. xl., 1865) by A. A. Julien, gives an account of the various phosphatic minerals

formed from the guano deposits on a coral island, Sombrero, in the Caribbean Sea.

Lord Byron, of the *Blonde*, mentions that phosphate of lime (apatite) was collected by him on Mauke, an elevated coral island of the Hervey Group, west of the Society Islands, but its exact condition in the rock is not stated.

Coral islands are exposed to earthquakes and storms like the continents, and occasionally a devastating wave sweeps across the land. During the heavier gales, the natives sometimes secure their houses by tying them to the cocoanut trees, or to a stake planted for the purpose. A height of ten or twelve feet, the elevation of their land, is easily overtopped by the more violent seas; and great damage is sometimes experienced. The still more extensive earthquake-waves, such as those which have swept up the coast of Spain, Peru, and the Sandwich Islands, would produce a complete deluge over these islands. We were informed by both Grey and Kirby, that effects of this kind had been experienced at the Gilbert Islands; but the statements were too indefinite to determine whether the results should be attributed to storms or to this more violent cause.

But while coral islands have their storms, the region in their vicinity is generally one of light winds and calms, even when the trades are blowing strongly all around them. The heated air which rises from the islands lifts the currents to a considerable height above the island. J. D. Hague mentions that on Jarvis's and the two neighbouring islands, under the equator, near 180° in longitude from Greenwich, he "often observed the remarkable phenomenon of a rain-squall approaching the island, and, just before reaching it, separating into two parts, one of which passed by on the north, the other on the south side, the cloud having been cleft by the column of heated air rising from the white coral sands."

CHAPTER IV.

GEOGRAPHICAL DISTRIBUTION OF CORAL REEFS AND ISLANDS.

THE distribution of coral reefs over the globe depends on the following circumstances, arising from the habitudes of polyps already explained.

1. The temperature of the ocean.
2. The character of coasts as regards (*a*) the depth of water,—(*b*) the nature of the shores,—(*c*) the presence of streams.
3. Liability to exposure to destructive agents, such as volcanic heat.

It has been stated (p. 255) that *reef-growing* corals will flourish in the hottest seas of the equator, and over the ocean, wherever the average temperature of the waters during the coldest month of winter is not below 68° F. The isothermal line of this temperature (or isocryme) forms, therefore, the boundary line of the coral-reef seas. Other corals not forming reefs grow in colder seas (p. 255), but to those we do not now refer.

This line traverses the oceans between the parallels 26° and 30°, or in general near 28°. But, as has been stated, in the vicinity of the continents it undergoes remarkable flexures from the influence of oceanic currents, the polar currents bending it toward the equator, while the tropical cause a divergence. From a comparison of the thermometrical

observations of various voyages with those of the Expedition, the author has been enabled to draw these boundary lines with a considerable degree of accuracy, and they are laid down upon the chart of the world published in his Report (Wilkes's Exploring Expedition) on Geology, and, with other isocrymal lines, on a full isocrymal chart of the globe, in his Report on Crustacea, from which it was reproduced in volume xv. (1853) of the second series of the *American Journal of Science*, which is now again issued at the close of this volume.

In the Pacific Ocean, this coral boundary, or isocryme of 68°, excludes the Galapagos from the coral seas, making a bend around them, and passing for a short distance even north of the equator, instead of near the parallel of 28° south, its position in mid-ocean. Captain Fitzroy, R.N., found the surface temperature of the sea at the Galapagos, from Sept. 16 to Oct. 18, 1835, 62° to 70° F. Oct. 23, in lat. 0° 30′ S., and long. 99° 4′ W., the temperature of the sea was 66° F.; Oct. 24, lat. 0° 23′ N., long. 96° 53′ W., temp. 70½°, 71½° F. While, under the equator, about the middle of the Pacific, the range of surface temperature of the sea through the year is 81° to 88° F.

On the side of Asia the boundary line bends far southward, and reaches the coast of Cochin China within 15° of the equator, although 30° from the equator a little to the eastward. On the west side of the Atlantic, the northern line starts at Cape Florida, in latitude 15° N., stretches abruptly northward, and bends around the Bermudas in latitude 33° N. On the African coast opposite, the northern line curves downward to the latitude of the Cape Verds, and the southern upward nearly to the equator. The following table gives the positions of the coral boundary lines where they meet the coasts of the continents:—

		Pacific Ocean.	Atlantic Ocean.
East side of ocean—	Northern,	Lat. 21° N	Lat. 10° N.
	Southern.	4° S	5° S.
West side of ocean—	Northern.	15° N.	26° N.
	Southern.	30° S., N. Holland. 29° S., Africa	22° S.

It follows from the above, that while the coral-reef seas are about fifty-six degrees wide in mid-ocean, they are

In the Pacific twenty-five degrees wide on the west coast of America, and forty-five degrees on the Asiatic side.

In the Atlantic, about fifteen degrees wide on the African coast, and forty-eight degrees on the coast of America.

If we reckon to the extremity of the bend in the Gulf Stream, the whole width of the coral-reef sea off the east coast of America will be over sixty-four degrees; while off the west coast of America the width is hardly eighteen degrees. It is obvious that these facts enable us to explain many seeming anomalies in the distribution of coral reefs.

The other causes which influence the distribution of reefs operate under this more general one of oceanic temperature, that is, within the coral-reef boundary lines. The effect of a deep abrupt coast on the distribution of reefs has been pointed out (p. 89). The unfavourable character of sandy or muddy shores, and the action of detritus, marine currents, and fresh waters have also been stated (p. 93), and it is not necessary to touch again upon these points.

Not less striking are the effects of *volcanic action* in preventing the formation of reefs; and instances of this influence are numerous throughout the Pacific. The existence of narrow reefs, or their entire absence, may often be thus accounted for. For example, in the Hawaian Group, the island of Hawaii, still active with volcanic fires, has but few traces of corals about it, while the westernmost islands, which have been longest free from such action, have reefs of considerable extent. The island of Maui exemplifies well the same general fact. The island consists of two peninsulas: one, the eastern, recent volcanic in character, with a large crater at summit; and the other, the western, presenting every evidence, in its gorges and peaks and absence of volcanic cones, of having become extinct ages since. In conformity with the view expressed, the coral reefs are confined almost exclusively to the latter peninsula. Other examples are afforded by the Samoan or Navigator Islands. Savaii abounds in extinct craters and lava

streams, and much resembles Hawaii in character; it bears proof in every part of being the last seat of the volcanic fires of the Samoan Group. Its reefs are consequently few and small: there is but a narrow line on part of the northern shores, although on the other islands they are very extensive.

This absence of corals results obviously from the destruction of the zoöphytes by heat, consequent on volcanic action. Submarine eruptions, which are frequent as long as a volcano near the sea is in action, heat the waters and destroy whatever of life they may contain. After the eruption of Kilauea, in 1840, there were numerous dead fish thrown on the beach; and many such instances in different regions are on record.

The agencies affecting the growth of coral reefs being before the mind, we may proceed to notice the actual distribution of reefs through the coral seas. The review given is a rapid one, as our present object is simply to explain the absence or presence of reefs within the coral-reef limits by reference to the above facts.

In the valuable work by Mr. Darwin, the geographical distribution of reefs is treated of at length. The facts here detailed have been obtained from independent sources, except where otherwise acknowledged. In accounting for the character and distribution of reefs, Mr. Darwin appears to attribute too much weight to a supposed difference in the change of level in different regions, neglecting to allow the requisite limiting influence to volcanic agency, and to the other causes mentioned. His conclusion that the areas of active volcanoes in general are areas of elevation, and not of subsidence, and the inference that reefs are absent from the shores of islands of recent volcanic action on this account do not accord with the facts above stated: for example, the condition of Maui, that it has no reefs on the larger half, that of the volcanic cone of recent action, but has them on the other half whose fires were long since extinct; for it is not probable that one end has been undergoing elevation and the other subsidence.

Pacific Ocean.—The west coast of South America is known to be without coral reefs even immediately beneath the

equator; and the seas of the Galapagos also grow no coral. The northward deflection of the coral boundary line accounts, as has been shown, for their absence. In the Bay of Panama, and elsewhere on the coast, north and south, corals occur in patches, but there are no reefs. There are corals also at La Paz, near the extremity of the peninsula of California (p. 86).

In Captain Colnett's voyage, allusion is made to a beach of coral sand on one of the Revillagigedo Islands, in latitude 18°; besides this statement we have met with no allusion to corals on any of the islands off the Mexican coast.

Between the South American coast and the Paumotus are two rocky islands, Easter or Waihu, and Sala-y-Gomez, both of which are stated to be without reefs.

Captain Beechey mentions, however, that at forty-one fathoms, near Sala-y-Gomez, he found a bottom of sand and coral.

The Paumotus commence in longitude 130° W., and embrace eighty coral islands, all of which, excepting about eight of small size, contain lagoons. Besides these, there are, near the southern limits of the archipelago, the Gambier Islands and Pitcairn, of volcanic or basaltic constitution. The former in 23° S., have extensive reefs. About the latter, in 25° S., there are some growing corals, but no proper reefs.

The Marquesas, in latitude 10° S., have but little coral about them; and this is the more remarkable, since they are in close proximity to the Paumotus. But their shores are mostly very abrupt, with deep waters close to the rocks. An island which, before subsidence has commenced, has some extent of shallow waters around, might have very bold shores after it had half sunk beneath the waves. This would be the case with the island of Tahiti; for its mountain declivities are, in general, singularly precipitous, except at the base. The Marquesas may, therefore, have once had barrier reefs, which were sunk from too rapid subsidence; and afterward, on the cessation of the subsidence, others failed to form again on account of the deep waters.

The Society Islands have extensive coral reefs with distant

barriers. The reefs of Tahiti extend in some parts a mile from the shores. Tetuaroa, to the north of Tahiti, and Tubuai, near Bolabola, are lagoon islands. Maitea, east of Tahiti, is a sugar loaf truncated at summit, four miles in compass, and is said by Forster to have an encircling reef.

South of the Society Islands, near 25° S., is Rapa, which is represented as a collection of rugged peaks without coral shores. The Rurutu and Hervey Islands, just north-west of Rapa, have coral reefs fringing the shores. There is no evidence of recent volcanic action among them. Some of them are elevated coral islands, as Mitiaro, Atiu, Mangaia and Mauki, and also, according to Stutchbury, Rurutu. Okatutaia is a low coral island but six or seven feet out of water.

Between the Paumotus and the longitude of Samoa are numerous small islands, all of coral origin.

The Samoan or Navigator Islands have extensive reefs. About Tutuila, owing to its abrupt shores, they are somewhat less extensive than around Upolu, and about Savaii they are still smaller, as already explained. The influence of abrupt shores may also be seen in some parts of Upolu; for example, to the west of the harbour of Falifa, where, for several miles, there is no reef, except in some indentations of the coast. Manua is described as having only shore reefs.

The Tonga Islands, south of Samoa, for the most part abound in coral reefs, and Tongatabu and the Hapai Group are solely of coral. Eoa is a moderately high island, with a narrow reef. Tafoa, an active volcano, and Kao, an extinct cone, are *without* reefs. Vavau, according to Williams (*Miss. Enterprises*, p. 427, Amer. ed.), is an elevated coral island. Pylstaarts, near Eoa, is a naked rock, with abrupt shores, and little or no coral. Sunday Island, farther south (29° 12′ S.), is beyond the coral-reef limits.

North of Samoa are several scattered islands of small size, all of coral.

The Feejee Group, already sufficiently described, abounds in reefs of great extent. There are no active volcanoes, and, where examined, no evidence of very recent volcanic action.

The many islands afford a peculiarly favourable region for the growth of zoöphytes, and the displays of reefs and living corals were the most remarkable seen by the author in the Pacific.

North of the Feejees are numerous islands leading up to the Carolines. They are all of coral, excepting Rotuma, Horne and Wallis's Islands, which are high, and have fringing or barrier reefs. The reefs of Wallis's Island are very extensive.

The Gilbert or Kingsmill Islands, the Marshall Islands, and the Carolines, about eighty in number, are all atolls, excepting the three Carolines, Ponape (Pouynipete of Lutke), Kusaie (or Ualan), and Truk (or Hogoleu). Between Ponape and Ualan, the McAskill Islands, three in number, are of coral, but sixty to 100 feet high (*Miss. Herald*, 1856, p. 193).

The westernmost of the Sandwich Islands, Kauai and Oahu, have fringing reefs, while eastern Maui and the island of Hawaii have but few traces of corals. On Hawaii, the only spot of reef seen by us was a submerged patch off the southern cape of Hilo Bay. We have already attributed the absence of corals to the volcanic character of the island. The small islands to the north-west of Kauai are represented as coral reefs, excepting the rocks Necker and Bird Island; the line stretches on to 28° 30′ N., the northern limit of the coral seas. *Lisiansky's Voyage*, 1803-'6 in the *Neva*, 4to., London, 1814, pp. 254, 256, contains an account of some of these islands; also the *Hawaian Spectator*, vol. i.; and also a "Report to the U. S. Bureau of Navigation," December, 1867, by Captain William Reynolds, U.S.N., partially reproduced in the *American Journal of Science* for 1871, vol. ii., p. 380.

The Ladrones, like the Hawaian Group, constitute a line or linear series of islands, one end of which has been long free from volcanic action, while the other has still its smoking cones. The appearances of recent igneous action increase therefore as we go northward, and the extent of the coral reefs increase as we go southward; no reefs occur about the northernmost islands, while they are quite extensive on the shores of

Guam. This group, consequently, like the Hawaian and Navigator, illustrates the influence of volcanic action on the distribution of reefs.

A short distance south-west of the Ladrones, and nearly in the same line, lie extensive reefs. Mackenzie's is an atoll of large size. Yap (or Eap), Hunter's, Los Matelotas and the Pelews (Palao), are high islands, with large reefs. In the last-mentioned, the reef-grounds cover at least six times the area occupied by the high land. Still farther south, toward New Zealand, lie the large atolls Aiou, Asie, and Los Guedes.

South of the equator again:—The New Hebrides constitute a long group of high islands, remarkable for the absence of coral reefs of any extent, though situated between two of the most extensive coral regions in the world—the Feejees and New Caledonia. But the volcanic nature of the group, and the still active fires of two vents in its opposite extremities, are a sufficient reason for this peculiarity. Tanna is one of the largest volcanoes of the Pacific; and nearly all the islands of the New Hebrides, as far as known, indicate comparatively recent igneous action, in which respect they differ decidedly from the Feejees.

The Vanikoro Group, north of the New Hebrides, according to Quoy, has large barrier reefs about the southernmost island, Vanikoro; but at the northern extremity of the range there is an active volcano, Tinakoro, and no coral. Tikopia, to the south-east of Vanikoro, is high and volcanic, according to Quoy, though not now with active fires; and it appears, from the descriptions given, to have no reefs. Mendana, north-east of Tinakoro, according to Kruesenstern, as stated by Darwin, is low, with large reefs; Duff's Islands have bold summits with wide reefs.

New Caledonia, and the north-east coast of New Holland, with the intermediate seas, constitute one of the grandest reef-regions in the world. On the New Caledonia shores (p. 106), the reefs are of great width, and occur not only along the whole length of the western coast, a distance of 200 miles, but

extend to the south beyond the mainland 50 miles, and north 150 miles, making in all a line of reef full 400 miles in length. Towards the north extremity, however, it is interrupted or broken into detached reefs. This surprising extent is partly explained by the fact that New Caledonia is not a land of volcanoes; but, on the contrary, consists of older metamorphic rocks. The streams of so large a land might be expected to exclude reefs from certain parts; and in accordance with this fact we find the reefs of the windward or rainy side comparatively small, and scarcely indicated on the charts; while on the dry or western side, they often extend thirty miles from the shores. The theory of subsidence accounts fully for the great prolongation of the New Caledonia reefs. The reefs indicate, moreover, the existence of a former land near three times the area of the present island.

Between New Caledonia and the New Hebrides are several high islands, one of which, Lafu, has been described (*Quart. Jour. Geol. Soc.*, 1847, p. 61) by Rev. W. B. Clarke as an elevated coral island, with fringing reefs; it appears also from the remarks of this writer, that the other islets of what is called the Loyalty Group are of the same kind. Lafu, the largest of the number, is about ninety miles in circumference.

South of New Caledonia lies Norfolk Island, in latitude 29° S., about which there is said to be some coral, which is occasionally thrown on the beach, but no reefs.

Between Australia and New Caledonia the islands are all of coral. The Australian reef extending south to the east cape, in latitude 24° S., has already been described. Such long reefs on the shores of continents are not common. In the case of Australia, the zoöphytes are not exposed to the destructive agents usual on continental shores, as the land has a dry climate, the shores are mostly rocky, and there are no streams of any extent emptying into the ocean. The east cape is the southern limit, because here the tropical current, owing to the direction of the coast above, trends off to the eastward of south, away from the land, while a polar current follows up the shores from the south as far as this

cape. South of this cape there are only a few scattered coral zoöphytes.

The Louisiade Group is described as a region of extensive reefs.

The Salomon Islands, as far as ascertained, are but sparingly fringed, except the two westernmost, which are said to have large reefs. The peculiar character of these lands is too imperfectly known to allow of our deducing the cause of so restricted reefs. Off to the north of the Salomon Islands there are several islands of considerable size. New Ireland, according to D'Urville, has distant reefs on part of its shores.

The Admiralty Islands, farther west, are inclosed by barrier reefs, and beyond this group there are a few lagoon islands.

The north side of New Guinea is mostly without coral. There are several islands off this coast, which are conical volcanic summits, and one of them, near New Britain, and another, Vulcano, near longitude 145° E., are in action.

From the facts thus far detailed, the connection between the prevalence or extent of reefs, and the various causes assigned as limiting or promoting their growth, is obvious. The amount of subsidence determines in some cases the distance of barrier reefs from shore; but it by no means accounts for the difference in their extent in different parts of a single group of islands. Indeed, if this cause be considered alone, every grade of extent, from no subsidence to the largest amount, might in many instances be proved as having occurred on a single island. Of far greater importance, as has appeared, is the volcanic character of the land. At whatever time the existing reefs in the Pacific commenced their growth, they began about those of the igneous islands whose fires had become nearly or quite extinct; and as others in succession were extinguished, these became, in their turn, the sites of corals, and of coral reefs. Those lands whose volcanoes still burn are yet without corals, or there are only limited patches on some favoured spots. Zoöphytes and volcanoes are the land-making

agents of the Pacific. The latter prepare the way by pouring forth the liquid rock, and building up the lofty summit. Quiet succeeds, and then commences the work of the zoöphyte beneath the sea, while verdure covers the exposed heights.

We may add a few more illustrations from other parts of the coral-reef seas.

Along the north and north-west coasts of Australia there appears to be little or no coral in the Gulf of Carpentaria, while some extensive patches occur on the shores west of this Gulf, as far as the north-west cape in latitude 23° S.

In the East Indies, there are large, scattered reef-islands south of Borneo and Celebes, about some of the Moluccas, and near the west end of New Guinea. The islands of Timor-laut, and Timor, with many of those intermediate, have large reefs. The Arru Group consists wholly of coral. This sea, from Arru, to the islands south of Borneo, is more thriving in corals than any other in the East Indies.

Another East Indian coral-reef region of some extent is the Sooloo Sea, between Mindanao and the north of Borneo. Yet the reefs are mostly submerged. The author saw no wide platforms bordering the high lands, like those of the Pacific. There are, however, some small coral islets in the Balabac Passage.

In other parts of the East Indies coral reefs are quite inconsiderable. Occasional traces, sometimes amounting to a fringing reef, occur along Luzon and the other Philippines.

The Wilkes Exploring Expedition coasted by the west shore of Luzon to Manila, and thence by Luban, Mindoro, Panay, to Caldera, near Samboangan in Mindanao; and through this distance no reefs were distinguished, as would have been the case had there been any of much extent. At the last-mentioned place we found coral pebbles on the beach, and, by dredging, obtained living specimens in six to eight fathoms of water. The only large reefs were those between Mindoro and the Calaminianes. There are fringing reefs at Singapore. The islands of Borneo, Celebes, Java, and Sumatra, according to all the authorities seen by the writer, have but few coral

patches about their shores, although affording long lines of coast for their growth. In the China Seas there are numerous shoals, banks, and island reefs of coral. Moreover, shore reefs occur about Loochoo, and the islands between it and Formosa. But the whole eastern coast of China appears to be without coral. Quelpaert's Island, south of Corea, in 34° N., is described as having coral about it; and this has been confirmed by late information.

Why should the reefs of the East India Archipelago be so limited in extent, and large parts be almost destitute, notwithstanding their situation in the warmest seas of the ocean and in the most favourable region for tropical productions? We are not prepared for a full answer to this inquiry; for it would demand a thorough knowledge of the shores, as well as of the currents, and of the former and present condition of volcanic fires. From personal observation we may reply satisfactorily as far as regards part of the southern half of the east coast of Sumatra. This coast is low and sandy, or muddy, and thus affords the most unfavourable place for zoöphytes. A strong current sweeps through the Straits of Banka, which keeps the water muddy, and the shores in constant change. The same cause may operate on the coasts of other islands, but we cannot say to what extent.

The East Indies have been remarkable for their volcanoes, exceeding, for the area, every other part of the world; and this fact must have had influence on the formation of coral reefs, though there are not data for fixing the extent of the influence. Of the thousand vents which have been in action, several still make themselves felt over wide areas. The Sooloo Islands are about one hundred in number, and nearly all are pointed with volcanic cones; and while some have the broken declivities that are marks of age, others have regular slopes, as if but just now extinguished; a dozen of these cones may sometimes be seen on a single island. These volcanic peaks often rise out of the sea, as if their formation had begun with a submarine eruption. In a region so extensively and so recently igneous, the coral polyps would have found little chance for growth, until

volcanic action had become comparatively quiet and deluges of hot water ceased. There appears, therefore, to be some reason for the fact that the reefs are small, and have seldom reached the surface. The Sooloo Group is but one of the volcanic clusters in these seas. Java, several of the Philippines, and other islands south of these last, with the northern shore of New Guinea, make up a wide region of fires, and it cannot be doubted that the frequent eruptions prevented the growth of anything more than isolated corals, for a long period, over each of these areas. For other causes we must look to the nature of the coasts, fresh-water streams, and marine currents; we leave it for other investigators to apply the explanation to particular coasts.

The coast of China owes its freedom from corals to the cool temperature of the waters, the coast being wholly outside, as has been stated, of the coral-reef seas.

One interesting fact should be noted:—the most extensive reefs in the East Indies are to be found in the open seas, between the large islands; these islands, at the same time, often being without proper reefs, or with mere traces of coral. This is the case between Borneo and the range of large islands south: the China Sea is another instance of it; north of New Guinea, a few degrees, is another. How far this is due to their being distant from the scenes of igneous action, and from the detritus and fresh water of island streams, remains to be determined. A sinking island becomes a more and more favourable spot for the growth of coral as it descends; for as its extent diminishes, its streams of fresh water and detritus also decrease. It might therefore be expected, on this account alone, that such isolated spots of land, away from all impure waters, in the open ocean, should become the bases of large reefs. The existence of these reef-islands is, therefore, no necessary proof of greater subsidence than the coast adjoining has undergone. Still the fact of a greater subsidence is not impossible or improbable.

In the *Indian Ocean*, the Asiatic coast is mostly free from growing coral. The great rivers of the continent are probably

the most efficient cause of their absence, both directly, through their fresh waters, and through the detritus they transport and distribute along the shores. It will be observed that this agent, so ineffectual on small islands, is one of vast influence upon larger lands. Mr. Darwin alludes to small patches of coral in the Persian Gulf. Ceylon has some fringing reefs.

The islands of the Indian Ocean are, to a great extent, purely of coral. Of this character are the Laccadives, Maldives, Keeling's, Saya-de-Malha, Almirante, and Cosmoledo. The Chagos Group is of the same character, and the shoal Cargados is probably similar. The Seychelles are small islands with extensive reefs.

Madagascar has a fringing reef upon its south-western point, according to Mr. Darwin, and on some parts of the coast above: also on the north and eastern shores far down as latitude 18° S. The Comoro Islands, between Madagascar and the continent, have large barrier reefs.

The eastern coast of Africa has narrow reefs extending north with some interruptions from Mozambique, in latitude 16° S., to a short distance from the equator. Corals also abound in the Red Sea, occurring in some parts on both shores, though most frequent on the eastern, from Tor, in the Gulf of Suez, to Konfodah. This long continental reef may at first be deemed a little remarkable, after what has been stated about such reefs elsewhere. Yet the surprise is at once set aside by the striking fact that this whole coast, from the Isthmus of Suez south, has no rivers, excepting some inconsiderable streams. It affords, therefore, an interesting elucidation of the subject under consideration, and confirms the view taken to account for the absence of reefs from many continental coasts. It is a fact almost universal, that where there are large fresh-water streams, there are earthy, or sandy shores; and where there are no such streams, rocky shores, though not uniformly occurring, are common.

On the African coast there are coral reefs at Port Natal, in latitude 30° S.; and here, owing to the warm currents from the

tropical regions, the mean winter temperature of the water is not below 68° F.

Passing from the Indian to the *Atlantic Ocean*, we find little or no coral on the west coast of Africa. The islands of Cape St. Ann and Sherboro, south of Sierra-Leone, are described as coral by Captain Owen, R.N., in the Journal of the Geographical Society (vol. ii., p. 89); but this has been since denied. The Island of Ascension, in 7° 56′ S., and 14° 16′ W., must have been bordered by growing coral, as Quoy and Gaymard mention that a bed of coral rock may be seen buried beneath streams of lava. Quoy also states that the corals which formed these reefs are no longer found alive, and adds that volcanic eruptions have probably destroyed them. The cold polar currents along the western African coast are the cause of the absence of corals from it, to within six or seven degrees of the equator; and these cold waters may at times extend still farther north. The same obstacle to the diffusion of species eastward, mentioned as occurring in the Pacific—that is, westward currents—exists also in the Atlantic, and probably with the same effect.

On the American shores of the Atlantic, north of the equator, there are few reefs, except in the West Indies. The waters of the Orinoco and Amazon, and the alluvial shores they occasion, exclude corals from that part of the coast.

In the West Indies, the reefs of Florida (p. 167), Cuba, the Bahamas (p. 174), and of many of the eastern islands, are well known. On the east coast of Florida they continue up as far as Cape Florida, in latitude 25° 40′ N.; but the west coast is free from them. There are also said to be patches at intervals along the coast of Venezuela and Guatemala; but the west shores of the Gulf of Mexico, as well as the northern, like West Florida, are mostly low, and without reefs; they are within the influence of the Mississippi and other large rivers. Some species of reef corals however occur in the vicinity of Aspinwall (p. 87). The Bermudas are of coral origin, and the most northern point of growing reefs.

South of the equator, on the east coast of South America,

there are reefs at intervals, from the vicinity of Cape St. Roque to the Abrolhos shoals in latitude 18°, as described by Prof. C. F. Hartt, while reef corals extend south to Cape Frio. Descriptions of part of the Abrolhos reefs are given on page 111. North of the Abrolhos reefs, there are others of coral stretching on to Point Carumba; again, off the Bay of Porto Seguro, and across the Bay of Santa Cruz; in the vicinity of Camamú, around Quieppe Island; along the shores of Itaparica Island; and at Bahia and Periperi; then, after an interruption, off Maceió, in the vicinity of Pernambuco. Moreover the Roccas, a cluster of reefs in the latitude of Fernando do Noronha, are, as Hartt observes, probably of coral.

It is thus seen that the earth is belted by a coral zone, corresponding nearly to the tropics in extent, and that the oceans throughout it abound in reefs, wherever congenial sites are afforded for their growth. It has also been shown that the currents of extra-tropical seas, which flow westward, and are interrupted and trended *toward* the equator by the continents, contract the coral seas in width, narrowing them to a few degrees on the western coasts of the continents; while the tropical currents flowing eastward, *diverge* from the equator, and cause the belt to widen near the eastern shores. The polar currents flow also by the eastern coasts, preventing the warmer waters from increasing the width of the coral zone as much as it is contracted on the western coasts. Moreover, the trend of the coast and its capes produce other modifications in the direction of the currents, the most of which are apparent in the actual distribution of coral reefs. On the shores of the continents it is observed that there are few extensive reefs, and the coasts on which they occur are those which, owing to the dryness of the climate, have no great rivers to pour fresh water and detritus into the sea. Thus the influence of continental waters and detritus on the distribution of reefs, is shown to be very marked. But about the Pacific Islands, where streams are small, the same cause has had little effect, seldom doing more than modifying somewhat the shores and

bottom of a harbour. It has been further demonstrated that in different groups, as the Ladrones, Sandwich Islands, Navigators, New Hebrides, there is an inverse relation between the extent of reefs and the evidences of recent volcanic action in the island; and that the largest reefs exist where there is no proof of former igneous action, or where it has long ceased. The existence of large reef-islands in open seas where the neighbouring lands are mostly destitute of coral reefs, harmonizes with the conclusions announced, since such islands are in general removed from the deleterious influences just mentioned; yet it is very possible that in some cases of this kind the region of the open sea may have undergone a subsidence not experienced equally by the lands on either side.

The modifications of form and interruptions of reefs, arising from abrupt or sloping shores, and tidal or local currents, have also been exemplified.

CHAPTER V.

ON CHANGES OF LEVEL IN THE PACIFIC OCEAN.

I. EVIDENCES OF CHANGE OF LEVEL.

It has been shown that atolls, and to a large extent other coral reefs, are registers of change of level. From the evidence thus afforded the bottom of a large part of the Pacific Ocean is proved to have undergone great oscillations in recent geological time. In this direction, then, we find the grandest teachings of coral formations. In treating the subject we necessarily bring into connection with it evidences of change of level from other sources. The proofs of change of level here considered are the following:—

A. Evidences of elevation.

1. *The existence on coral or other islands of patches of coral reef, and deposits of shells and sand from the reefs, above the level where they are at present forming.*

The coral reef-rock has been shown occasionally to increase, by growth of coral, to a height of four to six inches above low-tide level when the tide is but three feet, and to twice this height with a tide of six feet. It may therefore be stated as a general fact, that the limit to which coral *may grow* above ordinary low tide, is about one-sixth the height of the tide, though it seldom attains this height. Its existence on an island at a higher level would be proof of an elevation of the land.

When the tide is three feet, beach accumulations of large masses seldom exceed *eight* feet above high tide, and the finer fragments and sand may raise the deposit to *ten* feet; but with a tide of six feet twice this height may be attained. With the wind and waves combined, or on prominent points where these agents may act from opposite directions, such accumulations may be *fifteen* to *twenty* feet in height, and occasionally *thirty* to *forty* feet. These latter are drift deposits, finely laminated, generally with a sandy texture, and commonly without a distinguishable fragment of coral or shell; and in most of these particulars they are distinct from reef-rocks.

2. On islands not coral, *the existence of sedimentary deposits, or layers of rolled stones, interstratified among the layers of igneous or other rocks constituting the hills.*

B. Evidence of subsidence.

1. *The existence of wide and deep channels between an island and any of its coral reefs;* or in other words, *the existence of barrier reefs.*

2. *The existence of lagoon islands or atolls.*

3. *The existence of submerged atolls.*

4. *Deep bay-indentations in the coasts of high islands as the terminations of valleys.*—In the course of remarks upon the valleys of the Pacific Islands, presented by the author in his Geological Report, it is shown that they were in general formed by the waters of the land, unaided by the sea; that the sea tends only to fill up bays, level off the coast, and so give it an even outline. When, therefore, the several valleys of an island continue down *beneath* the sea, and their inclosing ridges stand out in long narrow points, with abrupt sides, there is reason to suspect that the island has subsided after the formation of its valleys. For such an island as Tahiti could not subside even a few scores of feet without changing the even outline into one of deep coves or bays, the ridges projecting out to sea on every side, like the spread legs of a spider. On the contrary, the absence of such coves, or deep-valley bays, may be evidence that no subsidence has taken place, or only one of comparatively small amount.

C. Probable evidence of subsidence now in progress.

1. *An atoll reef without green islets, or with but few small spots of verdure.*—The accumulation requisite to keep the reef at the surface-level, during a slow subsidence, renders it impossible for the reef to rise above the waves and supply itself with soil, unless the subsidence is extremely slow, or has wholly ceased.

From the above review of evidences of change of level, it appears that *where there are no barrier reefs, and only fringing reefs, the corals may afford no evidence of subsidence.* But it does not follow that the existence of only fringing reefs, or of no reefs at all, is proof *against* a subsidence having taken place. For we have elsewhere shown that through volcanic action, and at times other causes, corals may not have begun to grow till a recent period, and therefore we learn nothing from them as to what may have previously taken place. While, therefore, a distant barrier is evidence of change of level, we can draw no conclusion either one way or the other, as is done by Darwin, from the fact that the reefs are small or wholly wanting, until the possible operation of the several causes limiting their distribution has been duly considered.

The influence of volcanoes in preventing the growth of zoöphytes extends only so far as the submarine action may heat the water and it may therefore be confined within a few miles of a volcanic island, or to certain parts only of its shores.

There are two epochs of changes in elevation which may be here distinguished and separately considered. 1. The subsidence indicated by atolls and barrier reefs. 2. Elevations during more recent periods.

II. SUBSIDENCE INDICATED BY ATOLLS AND BARRIER REEFS.

Looking at atolls as covering buried islands, we observe, that through the equatorial latitudes such marks of subsidence abound, from the Eastern Paumotu to the Western Carolines, a distance of about six thousand geographical miles. In the

Paumotu Archipelago there are about eighty of these atolls. Going westward, a little to the north of west, they are found to dot the ocean at irregular intervals; and at the Kingsmill or Gilbert Group, the Marshall Group, and the Carolines, comprise seventy-five or eighty atolls.

If a line be drawn from Pitcairn's Island, the southernmost of the Paumotus, by the Gambier Group, the north of the Society Group, the Navigators, and the Salomon Islands to the Pelews, it will form nearly a straight boundary, trending N. 70° W., running between the atolls on one side and the high islands of the Pacific on the other, the former lying to the north of the line, and the latter to the south.

Between this boundary line and the Hawaian Islands, an area nearly two thousand miles wide and six thousand long, there are two hundred and four islands, of which *only three are high*, exclusive of the eight Marquesas, and the Ladrones, with Yap, Hunter's, and Los Matelotas in the line of the Ladrones and Pelews. These three are Kusaie or Ualan, Ponape, and Truk or Hogoleu, all in the Caroline Archipelago. South of the same line, within three degrees of it, there is an occasional atoll; but beyond this distance there are none, excepting the few in the Friendly Group and one or two in the Feejees.

If each coral island scattered over this wide area indicates the subsidence of an island, we may believe that the subsidence was general throughout the area. Moreover, each atoll, could we measure the thickness of the coral constituting it, would inform us nearly how much subsidence took place where it stands; for they are actually so many registers placed over the ocean, marking out, not only the sight of a buried island, but also the depth at which it lies covered. We have not the means of applying the evidence; but there are facts at hand which may give at least comparative results.

a. We observe, *first*, that the barrier reefs are, in general, evidence of less subsidence than atoll reefs (p. 229). Consequently, the great proponderance of the former just below the southern boundary line of the coral island area, and farther south the entire absence of atolls, while atolls prevail so

universally north of this line, are evidence of some depression just below the line; of less farther south; and of the greatest amount north of the line or over the coral area.

b. The subsidence producing an atoll, when continued, gradually reduces its size until it finally becomes so small that the lagoon is obliterated; and, consequently, a prevalence of these small islands is presumptive evidence of the greater subsidence. We observe, in application of this principle, that the coral islands about the equator, five or ten degrees south, between the Paumotus and the Gilbert Islands, are the smallest of the ocean; several of them are without lagoons, and some not a mile in diameter. At the same time, in the Paumotus, and among the Gilbert and Marshall Islands, there are atolls twenty to fifty miles in length, and rarely one less than three miles. It is probable, therefore, that the subsidence indicated was greater at some distance north of the boundary line, over the region of small equatorial islands, between the meridians of 150° W. and 180°.

c. When, after thus reducing the size of the atoll, the subsidence continues its progress, or when it is too rapid for the growing reef, it finally sinks the coral island, which therefore disappears from the ocean. Now it is a remarkable fact that while the islands about the equator, above alluded to, indicate greater subsidence than those farther south, there is over a region north of these islands, that is, between them and the Hawaian Group, a wide blank of ocean without an island which is nearly twenty degrees in breadth. This area lies between the Hawaian, the Fanning, and the Marshall Islands, and stretches off between the first and last of these groups, far to the north-west.

Is it not then a legitimate conclusion that the subsidence which was least to the south beyond the boundary line, and increased northward, was still greater or more rapid over this open area; that the subsidence which reduced the size of the islands about the equator to mere patches of reef was further continued, and caused the total disappearance of islands that once existed over this part of the ocean?

d. That the subsidence gradually diminished southwestwardly from some point of greatest depression situated to the northward and eastward, is apparent from the Feejee Group alone. Its north-east portion (see chart), consists of immense barriers, with barely a single point of rock remaining of the submerged land; while in the west and south-west there are mountain islands of great magnitude. Again, along the north side of the Vanikoro Group, Salomon Islands, and New Ireland, there are coral atolls, but scarcely one to the south.

In view of this combination of evidence, we cannot doubt that the subsidence increased from the south to the northward or north-eastward, and was greatest between the Navigator and Hawaian Islands, near the centre of the area destitute of islands, about longitude 170° to 175° W., and 8° to 10° N.

But we may derive some additional knowledge respecting this area of subsidence from other facts.

Hawaian Range.—We observe that the western islands in the Hawaian Range, beyond Bird Island, are atolls, and all indicate a large participation in this subsidence. To the eastward in the range, Kauai and Oahu have only fringing reefs, yet in some places these reefs are half a mile to three-fourths in width. They indicate a long period since they began to grow, which is borne out by the features of Kauai showing a long respite from volcanic action. We detect proof of subsidence, but not of a large amount. Moreover, there are no deep bays; and besides, Kauai has a gently-sloping coast plain of great extent, with a steep shore acclivity of one to three hundred feet, all tending to prove the smallness of the subsidence. We should, therefore, conclude that these islands lie near the limits of the subsiding area, and that the change of level was greatest at the western extremity of the range beyond Kauai.

The coral subsidence of the western islands of the range bear some evidence of having in recent times commenced a new subsidence. They all have little dry land and vegetation about the reefs. *Brooks's Island*, in latitude 28° 15′ and longitude 177° 20′ W., eighteen miles in circumference, has on its

north and east sides a compact coral wall of about five feet elevation, which continues for four and a quarter miles, and then becomes a line of detached rocks at tide level. This bare wall, thus described by Capt. Wm. Reynolds, U.S.N., appears to be an indication that the land was once finished off under a cessation of subsidence, but that a sinking of small amount has since taken place, amounting perhaps to *four* or *five* feet.

Ocean Island, in 28° 25′ N., 178° 25° W., another of this range, is very similar to Brooks's in its wall of coral rock on the east; and so also is *Pearl* and *Hermes'* reef, in 27° 50′ N., 176° W., though the wall of the latter is more a series of detached rocks than a continuous parapet.

Marquesas.—The Marquesas are remarkable for their abrupt shores, often inaccessible cliffs, and deep bays. The absence of gentle slopes along the shores, their angular features, abrupt soundings close alongside the island, and deep indentations, all bear evidence of subsidence to some extent; for their features are very similar to those which Kauai or Tahiti would present if buried half its height in the sea, leaving only the sharper ridges and peaks out of water. They are situated but five degrees north of the Paumotus, where eighty islands or more have disappeared, including one at least fifty miles in length. There is sufficient evidence that they participated in the subsidence of the latter, but not to the same extent. They are nearly destitute of coral, and apparently because of the depth of water about the islands.

Gambier Group.—In the southern limits of the Paumotu Archipelago, where, in accordance with the foregoing views, the least depression in that region should have taken place, there are actually, as we have stated, two high islands, *Pitcairn's* and *Gambier's*. There is evidence, however, in the extensive barrier about the *Gambier's* (see cut on page 227), that this subsidence, although less than farther north, was by no means of small amount. On page 126, we have estimated it at 1,150 feet—possibly 1,750. These highlands therefore, although toward the limits of the subsiding area, were still

far within it. The valley-bays of the islets of the lagoon are of great depth, and afford additional evidence of the subsidence.

Tahitian Islands.—The Tahitian Islands, along with Samoa and the Feejees, are near the southern limits of the area pointed out. Twenty-five miles to the north of Tahiti, within sight of its peaks, lies the coral island Tetuaroa, a register of subsidence. Tahiti itself, by its barrier reefs, gives evidence of the same kind of change; amounting, however, as we have estimated, to a depression of but two hundred and fifty or three hundred feet. The north-western islands of the group lie more within the coral area, and correspondingly, they have wider reefs and channels, and deep bays, indicating a greater amount of subsidence.

Samoan or *Navigator Group.*—The island of Upolu has extensive reefs, which in many parts are three-fourths of a mile wide, but no inner channel. The subsidence is estimated on page 126, at one or two hundred feet. The volcanic land west of Apia declines with an unbroken gradual slope of one to three degrees beneath the sea. The absence of a low cliff is probable evidence of a depression, as has been elsewhere shown. The island of Tutuila has abrupt shores, deep bays, and little coral. It appears probable, therefore, that it has experienced a greater subsidence than Upolu. Yet the central part of Upolu has very similar bays on the north, which would afford apparently the same evidence; and it is quite possible that the facts indicate a sinking which either preceded the ejections that now cover the eastern and western extremities of Upolu, or accompanied this change of level. The large island of Savaii, west of Upolu, has small reefs, small because probably of volcanic action; for it bears, everywhere, evidence of comparatively recent eruption; from it, therefore, we gather no certain facts bearing on this subject. East of Tutuila is the *coral island*, Rose. It may be, therefore, that the greatest subsidence in the group was at its eastern extremity.

Feejee Islands.—We have already remarked upon this group

(p. 127). A large amount of subsidence is indicated by the extensive reefs in every portion of the group, but it was greatest beyond doubt in the north-eastern part. The subsidence, where least, could hardly have been less than 2,000 to 3,000 feet.

Ladrones.—The Ladrones appear to have undergone their greatest subsidence at the northern extremity of the range, the part nearest the centre of the coral area; for although the fires at the north have continued longest to burn, the islands are the smallest of the group, the whole having disappeared except the summits, which still eject cinders. The southern islands of the group have wide reefs, which show that they participated to some extent in the subsidence; and this is further indicated by the islands lying to the south-west, in the line of the Ladrones.

We have thus followed around the borders of the coral area; and, besides proving the reality of the limits, have ascertained some facts with reference to a gradual diminution of the subsidence toward, and beyond, these limits. A line through the Hawaian Group would pass along the northern boundary line of the area; and taking the southern boundary as given on page 273, the oblong area narrows eastward. An axis nearly bisecting this space, drawn from the eastern Paumotus toward Japan, passes through the region of greatest subsidence, as above determined, and may be considered the *line of greatest depression* for the great area of subsidence.

It is worthy of special note, *that this axial line, or line of greatest depression, coincides in direction with the mean trend of the great ranges of islands, it having the course* N. 52° W.; and it also corresponds approximately with the axial line of the Pacific ocean.

The southern boundary line of the coral area, as we have laid it down, lies within the area of subsidence, although near its limits. This area has been prolonged south-eastward in some places beyond the boundary line. One of the regions of this prolongation lies between the Samoan or Navigator Group and the Feejees and Tonga Group; another is east of

Samoa, along by the Hervey Group. Each of these extensions *trends parallel with the groups of islands.* It would seem, therefore, that the Society and Samoan islands were regions of less change of level than the deep seas on either side of them; that therefore, instead of a uniform subsidence over the subsiding area shading off toward the borders, there were troughs of greater subsidence, whose courses were parallel to the ranges of islands; that, in other words, there were in the ocean's bottom a few broad synclinal and anticlinal flexures, having a common direction nearly parallel to the axial line of the Pacific. The Marquesas and Fanning Groups lie in a common line, and thus may mark the course of a great central anticlinal in the oceanic basin.

The Hawaian range has experienced its greatest subsidence to the north-west, where the islands are all atolls, and show some evidences of recent sinking; and this north-western extremity of the range is nearer to the axis of the area of subsidence, above laid down, than is the south-western.

What is the extent of the subsidence indicated by the coral reefs and islands of the Pacific? It is very evident that the sinking of the Society, Samoan, and Hawaian Islands has been small compared with that required to submerge all the lands on which the Paumotus and the other Pacific atolls rest. One, two, or five hundred feet, could not have buried the many peaks of these islands. Even the 1,200 feet of depression at the Gambier Group is shown to be at a distance from the axis of the subsiding area. The groups of high islands above mentioned contain summits from 4,000 to 14,000 feet above the sea; and can we believe it possible that throughout this large area, when the two hundred islands now sunken were above the waves, there were none of them equal in altitude to the mean of these heights, or 9,000 feet? That none should have exceeded 9,000 feet in elevation is by no means probable. Hence, however moderate our estimate, there must still be allowed a sinking of many thousand feet. Moreover, whatever estimate we make that is within probable bounds, we shall not arrive at a more surprising change of level than our continents

show that they have undergone; for since the Tertiary began (or the preceding period, the Cretaceous, closed) more than 10,000 feet have been added to the Rocky Mountains, and parts of the Andes, Alps, and Himalayas.

Between the New Hedrides and Australia the reefs and islands mark out another area of depression, which may have been simultaneously in progress. The long reef of one hundred and fifty miles from the north cape of New Caledonia, and the wide barrier on the west, cannot be explained without supposing a subsidence of one or two thousand feet at the least. The distant barrier of Australia is proof of great subsidence, even along the border of that continent. But the greatest amount of sinking took place, in all probability, over the intermediate sea, called the "Coral Sea," where there are now a considerable number of atolls.

III. EFFECT OF THE SUBSIDENCE.

The facts surveyed give us a long insight into the past, and exhibit to us the Pacific once scattered over with lofty lands, where now there are only humble monumental atolls. Had there been no growing coral, the whole would have passed without a record. These permanent registers exhibit in enduring characters some of the oscillations which the "stable" earth has since undergone.

From the actual size of the coral reefs and islands, we know that the whole amount of high land lost to the Pacific by the subsidence was at the very least fifty thousand square miles. But since atolls are necessarily smaller than the land they cover, and the more so, the further subsidence has proceeded; since many lands, owing to their abrupt shores, or to volcanic agency, must have had no reefs about them, and have disappeared without a mark; and since others may have subsided too rapidly for the corals to retain themselves at the surface; it is obvious that this estimate is far below the truth. It is apparent that, in many cases, islands now disjoined have been once connected, and thus several atolls may have been made

about the heights of a single subsiding land of large size. Such facts show additional error in the above estimate, evincing that the scattered atolls and reefs tell but a small part of the story. Why is it, also, that the Pacific Islands are confined to the tropics, if not that beyond thirty degrees the zoöphyte could not plant its growing registers?

The island of Ponape, in the Caroline Archipelago, affords evidence of *a subsidence in progress*, as Mr. Horatio Hale, the Philologist of the Wilkes Expedition, gathered from a foreigner who had been for a while a resident on this island. Mr. Hale remarks, after explaining the character of certain sacred structures of stone: "It seems evident that the constructions at Ualan and Ponape are of the same kind, and were built for the same purpose. It is also clear, that when the latter were raised, the islet on which they stand was in a different condition from what it now is. For at present they are actually in the water; what were once paths are now passages for canoes, and as O'Connell [his informant] says, 'when the walls are broken down, the water enters the inclosures.'" Mr. Hale hence infers "that the land, or the whole group of Ponape, and perhaps all the neighbouring groups, have undergone a slight depression." He also states respecting a small islet near Ualan: "From the description given of Leilei, a change of level of one or two feet would render it uninhabitable, and reduce it, in a short time, to the same state as the isle of ruins at Ponape."

In some of the northern Carolines, the Pescadores, and perhaps some of the Marshall Islands, the proportion of dry land is so very small compared with the great extent of the atoll, that there is reason to suspect a slow sinking even at the present time; and it is a fact of special interest in connection with it, that this region is near the axial line of greatest depression, where, if in any part, the action should be longest continued.

Among the Kingsmills and Paumotus, there is no reason whatever for supposing that a general subsidence is still in progress; the changes indicated are of a contrary character.

IV. PERIOD OF THE SUBSIDENCE.

The period during which these changes were in progress extends back to the Tertiary era, and perhaps still farther. In the island of Metia, elevated two hundred and fifty feet, the corals below were the same as those now existing, as far as we could judge from the fossilized specimens. At the inner margin of shore reefs there is the same identity with existing genera. We do not claim to have examined the basement of the coral islands, and offer these facts as the only evidence on this point that is within reach. We cannot know with absolute certainty that the present races of zoöphytes may not be the successors of others that flourished, on the same sites, even before the Tertiary era in Cretaceous and Jurassic times; but as yet have little reason, in facts observed, for such a conclusion. For a long time volcanic action may have been too general and constant over the Pacific for the growth of corals; and this may have continued to interfere till a comparatively late period, if we may judge from the appearance of the rocks, even on Tahiti. The subsidence has probably for a considerable period ceased in most, if not all, parts of the ocean, and subsequent elevations of many islands and groups have taken place.

V. ELEVATIONS OF MODERN ERAS IN THE PACIFIC.

Since the period of subsidence discussed in the preceding pages, there has been no equally general elevation. Yet various parts of the ocean bear evidence of changes confined to particular islands, or groups of islands. While the former exemplify one of the grander events in the earth's history, in which a large segment of the globe was concerned, the latter exhibit its minor changes over limited areas. The instances of these changes are so numerous and so widely scattered, that they afford convincing evidence of a cessation in the previous general subsidence.

The most convenient mode of reviewing the subject is to state in order the facts relating to each group.

a. Paumotu Archipelago.—The islands of this archipelago appear in general to have that height which the ocean may give to the materials. Nothing was detected indicating any *general* elevation in progress through the archipelago. The large extent of wooded land shows only that the islands have been long at their present level; and on this point the author's observations confirm those of Mr. Darwin. There are examples of elevation in particular islands, however, some of which are of unusual interest. The instances examined by the Expedition are those of Honden Island (or Henuake), Dean's Island (or Nairsa), Aurora (or Metia), and Clermont Tonnerre. Besides these, Elizabeth Island has been described by Beechey, and the same author mentions certain facts relating to Ducie's Island and Osnaburgh, which afford some suspicions of a rise.

Honden Island or *Henuake.*—This island is wooded on its different sides, and has a shallow lagoon. The beach is eight feet high, and the land about twelve. There are three entrances to the lagoons, all of which were dry at low water, and one only was filled at high water. Around the lagoon, near the level of high tide, there were numerous deserted shells of the huge Tridacna, often a foot long, lying in cavities in the coral rock, precisely as they occur alive on the shore reef. As these Tridacnas evidently lived where the shells remain, and do not occur alive more than six or eight inches, or a foot at the most, above low tide, they prove, in connection with the other facts, an elevation of at least *two* feet.

Nairsa or *Dean's Island.*—The south side of Dean's Island, the largest of the Paumotus, was coasted along by the *Peacock*, one of the Sloops of War of the Wilkes Exploring Expedition, and from the vessel we observed that the rim of land consisted for miles of an even wall of coral rock, apparently six or eight feet above high tide. This wall was broken into rude columns, or excavated with arches and caverns; in some places the sea had carried it away from fifty to one hundred rods, and then

there followed again a line of columns, and walls, with occasional arches as before. The reef, formerly lying at the level of low tide, had been raised above the sea, and subsequently had undergone degradation from the waves. The standing columns had some resemblance in certain parts to the masses seen here and there on the shore platforms of other islands; but the latter are only distantly scattered masses, while on this island, for the greater part of the course, there were long walls of reef-rock. The height, moreover, was greater, and they occurred too on the *leeward* side of the island, ranging along nearly its whole course, while the north side, according to the map, *is wooded throughout.*

The elevation here indicated is at least *six* feet; but it may have been larger; the observations were made from shipboard.

Thirty miles to the southward of Dean's Island we came to Metia, one of the most remarkable examples of elevation in the Pacific.

Metia.—This island has already been described, and its elevation stated at *two hundred and fifty* feet. (See page 157.)

Clermont Tonnerre shows the same evidence of elevation from Tridacnas as Honden Island. Clermont Tonnerre and Honden are on the north-eastern limits of the Paumotus.

Elizabeth Island was early shown to be an elevated coral island by Beechey. This distinguished voyager represents it as having perpendicular cliffs over fifty feet in height. From his description it is obviously like Metia; the elevation is *eighty* feet. It is one of the south-eastern Paumotus, near Ducie's.

Ducie's Island is described by Beechey as twelve feet high, which would indicate a probable elevation of *one* or *two* feet.

Osnaburgh Island, according to the same author, affords evidence of having increased its height since the wreck of the *Matilda*, in 1792. He contrasts the change from a "reef of rocks," as reported by the crew, to a "conspicuously wooded island," the condition when he visited it; and states, further, that the anchor, ironworks, and a large gun (4-pounder) of this

vessel were two hundred yards inside of the line of breakers. Captain Beechey suggests that the coral had grown, and thus increased the height. But this process might have buried the anchor if the reef were covered with growing corals (which is improbable), and could not have raised its level. If there has been any increase of height (which we do not say is certain), it must have arisen from an upheaval.

b. Tahitian Group.—The island of Tahiti presents no conclusive evidence of elevation. The shore plains are said to rest on coral, which the mountain débris has covered; but they do not appear to indicate a rise of the land.

The descriptions by different authors of the other islands of this group do not give sufficient reason for confidently believing that any of them have been elevated. The change, however, of the barrier reef around Bolabola into a verdant belt encircling the island may be evidence that a long period has elapsed since the subsidence ceased; and, as such a change is not common in the Pacific, we may suspect that it has been furthered by at least a small amount of elevation. The observation by the Rev. D. Tyerman with regard to the shells found at Huahine high above the sea, may be proof of elevation; but the earlier erroneous conclusions with regard to Tahiti (on which island masses of coral are carried by natives up the mountain, to leave at the highest point reached, and also to mark the limits between the land of different chiefs, and are common from these causes, up to a height of fifteen hundred feet), teach us to be cautious in admitting it without a more particular examination of the deposit. Moreover, shells, even large ones, are carried far away from the sea by Hermit Crabs (Pagurids).

c. Hervey and *Rurutu Groups.*—These groups lie to the south-west and south of Tahiti.

Mangaia is girted by an elevated coral reef *three hundred* feet in height. Mr. Williams, in his *Missionary Enterprises* pages 48, 50, and 249, speaks of it as coral, with a small quantity of fine-grained basalt in the interior of the island; he states again that a broad ridge (the reef) girts the hills.

Atiu (Wateoo of Cook) is a raised coral island. Cook (*Voy.*, i. 180, 197) observes that it is "nearly like Mangaia." The land near the sea is only a bank of coral ten or twelve feet high, and steep and rugged. The surface of the island is covered with verdant hills and plains, with no streams. It is described by Williams in his *Missionary Enterprises*. *Mauke* is a low elevated coral island according to Williams, and *Mitiaro* resembles Mauke. *Okatutaia* is a low coral island, not more than six or seven feet high above the beach, which is coral sand. It has a light-reddish soil.

Rurutu has an elevated coral reef *one hundred and fifty* feet in height, as stated by Stutchbury, and also Williams. Tyerman and Bennet describe the island as having a high central peak with lower eminences, and speak of the coral rock as *two hundred* feet high on one side of the bay and *three hundred* on the other (ii. 102).—Ellis says that the rocks of the interior are in part basaltic, and in part vesicular lava (iii. 393).

With regard to the other islands of these groups, *Manuai*, *Aitutaki*, *Rarotonga*, *Rimetara*, *Tubuai*, and *Raivavai*, the descriptions by Williams and Ellis appear to show that they have undergone no recent elevation.

d. Tonga or *Friendly Islands, and others in their vicinity.*

All the islands of the Tonga Group about which there are reefs give evidence of elevation: *Tongatabu* and the *Hapaii* islands consist solely of coral, and are elevated atolls.

Eua, at the south extremity of the line, has an undulated mostly grassy surface, in some parts eight hundred feet in height. Around the shores, as was seen by us from shipboard, there is an elevated layer of coral reef-rock, twenty feet thick, worn out into caverns, and with many spout-holes. Between the southern shores and the highest part of the island we observed three distinct terraces. Coral is said to occur at a height of *three hundred* feet. From the appearance of the land, we judged that the interior was basaltic; but nothing positive was ascertained with regard to it.

Tongatabu (an island visited by us) lies near Eua, and is in some parts fifty or sixty feet high, though in general but

twenty feet. It has a shallow lagoon, into which there are two entrances; some hummocks of coral reef-rock stand eight feet out of water.

Namuka and most of the *Hapaii* cluster, are stated by Cook to have abrupt limestone shores, ten to twenty feet in height. Namuka has a lagoon or salt lake at centre, one and a half miles broad; and there is a coral rock in one part twenty-five feet high. It is described by Williams (p. 296).

Vavau, the northern of the group, according to Williams (p. 427), is a cluster of elevated islands of coral limestone, thirty to one hundred feet in height, having precipitous cliffs, with many excavations along the coast.

Pylstaart's Island, south of Tongatabu, is a small rocky islet without coral. *Tafua* and *Proby* are volcanic cones, and the former is still active.

Savage Island, a little to the east of the Tonga Group, resembles Vavau in its coral constitution and cavernous cliffs It is elevated, according to Williams (pp. 275, 276), *one hundred* feet.

Beveridge Reef, a hundred miles south-east of Savage, is low coral.

e. Samoan or *Navigator Islands.*—No satisfactory evidences of elevation were detected about these islands.

f. Atolls, north of Samoa.

On account of the high tides (four to six feet), the sea may give a height of twelve to sixteen feet to the land.

Swain's, near latitude 11° S., is fifteen to eighteen feet above the sea where highest, and the beach is ten to twelve feet high. It is a small island, with a depression at centre, but no lagoon. Probably an elevation of *two* or *three* feet.

Fakaafo, ninety miles to the north, is fifteen feet high. The coral reef-rock is raised in some places three feet above the present level of the platform. Elevation at least *three* feet.

Nukunono, or Duke of Clarence, near Fakaafo, was seen only from shipboard.

Oatafu, or Duke of York's, is in some parts fourteen feet

high. Whether elevated or not is uncertain; probably as much so as Fakaafo.

g. Scattered islands farther north, near the equator, east of the Gilbert Group.

Of the Fanning Group, *Washington Island*, in lat. 4° 41′ S., and 160° 15′ W., is three miles in diameter, and is without a proper lagoon; the whole surface is densely covered with cocoanut and other trees. The height of the land is ten or twelve feet. The unusual size of the island for one without a lagoon, and the luxuriance of the forest vegetation, are probable evidence of some elevation, but not beyond *three* feet.

Palmyra Island, north-east of Washington, is described by Fanning as having two lagoons, the westernmost with twenty fathoms water.

Fanning's Island, south-east of Washington, according to the same voyager, is lower than that island. The accounts give no evidence of elevation in either Fanning's or Palmyra.

Christmas Island, in lat. 1° 53′ N., 157° 32′ W., is thirty miles long, and is described by Cook as having the rim of land in some parts three miles wide. He speaks of narrow ridges lying parallel with the sea-coast, which "must have been thrown up by the sea, though it does not reach within a mile of some of these places." The proof of elevation is decided, but its amount is uncertain. The account of J. D. Bennett (*Geogr. Journ.*, vii. 226) represents it as a low coral island.

Jarvis's Island, in 0° 22′ S., and 159° 58′ W., is, according to J. D. Hague, eighteen to twenty-eight feet in height, which would indicate an elevation of at least eight or ten feet. (See further, page 248.)

Malden's, in 4° 15′ S., 155° W., two hundred and fifty miles south-east of Jarvis, visited by Lord Byron, is described by him as not over *forty* feet high. It is ten miles long.

Starbuck's or *Hero Island*, in 5° 40′ S., 155° 55′ W., is an elevated lagoon island; but the amount of elevation is not stated. Like Jarvis's, it contains a large deposit of gypsum, but not much guano.—(J. D. Hague.)

Penrhyn's Island, near 9° S. and 157′ W., has a length of nine miles, and an extensive lagoon with a boat entrance into it. According to Captain Ringgold of the Wilkes Expedition, it has a height of fifty feet, which, if correct, would indicate an elevation of full *thirty-five* feet. The north-west side is, throughout, a cocoanut grove.

Flint's Island, in 11° 26′ S., and 151° 48′ W., is only a mile and a half long, but is thickly wooded, according to Captain Ringgold, which is unusual for so small an island

Staver's Island, in 10° 5′ S., and 152° 22½′ W., is only half a mile across, and yet is well wooded. Both of these islands were passed by Captain Ringgold, but he does not state the height.—(Wilkes's Narr., iv. 277.)

Baker's Island, 0° 13′ N., 176° 22′ W., is one mile long and two-thirds of a mile wide. The greatest height, according to J. D. Hague, is twenty-two feet, "showing some evidences of elevation." (See further, p. 247.) It has probably been elevated at least *six* feet.

Howland's Island, 0° 51′ N., and 176° 32′ W., is about forty miles north of Baker's. It is about one and half miles long, and half a mile wide. The highest point, according to Hague, is ten or twelve feet above high-tide level; which is evidence of but little if any elevation. It is a guano island, like Baker's.

McKean's Island, of the Phœnix Group (like Phœnix, Enderbury, and Birnie's), in 3° 35′ S., 174° 17′ W., is a low island, according to Hague, circular in form, *one-quarter* of a mile in diameter, but less elevated than Jarvis's Island. It has a lagoon depression, in which there is a gypsum and guano deposit; at high tides the guano is sometimes two feet under water. *Phœnix's Island*, near McKean's, 3° 40′ S., 170° 52′ W., is less than half a mile in diameter, and the border is only eight or ten feet high; so that there is no evidence in the height of an elevation. It is also a guano island.

Enderbury's, in 3° 8′ S., 174° 14′ W., is eighteen feet high. It has probably experienced some elevation. But the height of the tides is such in the seas as to give the beach and drift

sands much greater height than they have in the Paumotus. *Birnie's Island* is a small bank of coral, only six feet above the sea, according to Wilkes (Narr. v. 4).

Gardner's, *Hull's*, *Sydney*, and *Newmarket* were visited by the Wilkes Expedition. No satisfactory evidences of elevation were observed on the first three. Newmarket is stated by Captain Wilkes to have a height of *twenty-five* feet, which would indicate an elevation of six or eight feet.

h. Sandwich or Hawaian Islands.—*Oahu* affords decisive proof of an elevation of twenty-five or thirty feet. There is an impression at Honolulu, derived from a supposed increasing height in the reef off the harbour, that the island is slowly rising. Upon this point we have nothing satisfactory. The present height of the reef is not sufficiently above the level to which it might be raised by the tides, to render it certain, from this kind of evidence, that the suspected elevation is in progress.

Kauai presents us with no evidence that the island, at the present time, is at a higher level than when the coral reefs began; or, at the most, no elevation is indicated beyond a foot or two. The drift sand-rock of Koloa appears to be a proof of elevation, from its resemblance to that of Northern Oahu; but if so, there must have been a subsidence since, as it now forms a cliff on the shore that is gradually wearing away.

Molokai, according to information from the Rev. Mr. Andrews, has coral upon its declivities three hundred feet above the sea.

Mr. Andrews, in his communication, informed the author that the coral occurs "upon the acclivity of the eastern or highest part of the island, over a surface of more than twenty or thirty acres, and extends almost to the sea. We had no means of accurately measuring the height; but the specimens were obtained at least thre heundred feet above the level of the sea, and probably four hundred. The specimens have distinctly the structure of coral. The distance from the sea was two to three miles."

Coral has been reported to occur on the western peninsula of *Maui*, in some places eight hundred feet above the sea; but according to C. F. Winslow, the supposed coral does not effervesce with acids, and therefore is not calcareous.

There are large masses of coral rock, according to Mr. Andrews, along the shores of Maui, from *two* to *twelve* feet above high water. From his descriptions, this rock appears to be the reef-rock, like the raised reef of Oahu, and is probably proof of an elevation of at least *twelve* feet.

On page 277, it is suggested that the westernmost coral islands of the Hawaian range, Ocean and Brooks's Islands, may have undergone a small subsidence. Should the broken wall of emerged rock turn out, on examination, to be coral reef-rock, instead of the beach sand-rock, the facts would prove an elevation of a few feet, instead of a subsidence. The islands differ from Dean's, in having no long range of wooded land on the windward side.

i. Feejee Islands.—The proofs of an elevation of four to six feet about the larger Feejee Islands, Viti Lebu and Vanua Lebu, and also Ovalau, are given in the author's report on this group. How far this rise affected other parts of the group he was unable definitely to determine; but as the extensive barrier reefs in the eastern part of the group rarely support a green islet, they rather indicate a subsidence in those parts than an elevation.

j. Islands north of the Feejees.—Horne Island, Wallis, Ellice, Depeyster, and four islands on the track toward the Kingsmills, were passed by the sloop of war *Peacock* of the Wilkes Expedition; but from the vessel no evidences of elevation could be distinguished. The first two are high islands, with barriers, and the others are low coral. S. J. Whitnell, Esq., has recently stated that at Ellice Island (or Funafuti), "on the windward side of the largest island of the atoll, there is a small lagoon (dry at low water), shut in from the sea by a wall twenty feet high, consisting of large masses of coral;" and he regards this as evidence of some elevation. Moreover, on the reef, which is a narrow ledge, "compact masses of coral rock were observed

in situ rising four feet above low-water mark." *Rotuma* (177° 15′ E., and 12° 30′ N.) is another high island, to the west of Wallis's. It has encircling reefs, but we know nothing as to its changes of level.

k. Kingsmill or *Gilbert Group.* (Map, p. 133.)

Tapateuea or *Drummond.*—This is one of the southern islands of the group. The reef-rock, near the village of Utiroa, is a foot above low-tide level, and consists of large massive Astræas and Mæandrinas. The tide in the Kingsmill seas is seven feet; and consequently this evidence of a rise might be doubted, as some corals may grow to this height where the tide is so high. But these Astræas and Mæandrinas, as far as observed by the writer, are not among the species that may undergo exposure at low tide, except it be to the amount of three or four inches; and it is probable that an elevation of at least one foot has taken place.

Apaiang or *Charlotte's* Island, one of the northernmost of the group, has the *reef-rock* in some parts raised bodily to a height of six or seven feet above low-water level, evidencing this amount of elevation. This elevated reef was observed for long distances between the several wooded islets; it resembled the south reef of Nairsa in the Paumotu Archipelago in its bare, even top, and bluff, worn front. An islet of the atoll, where we landed, was twelve feet high, and the coral *reef-rock* was five or six feet above middle tide. A wall of this rock, having the same height, extends along the reef from the islet. There was no doubt that it was due to an actual uplifting of the reef to a height of full *six* feet.

Nononti, *Kuria*, *Maiana*, and *Tarawa*, lying between the two islands above mentioned, were seen only from the ship, and nothing decisive bearing on the subject of elevation was observed. On the north-east side of Nononti there was a hill twenty or thirty feet in height covered with trees; but we had no means of learning that it was not artificial. We were, however, informed by Kirby, a sailor taken from Kuria, that the reef of *Apamama* was elevated, precisely like that of Apaiang, to a height of *five* feet; and this was confirmed by Lieutenant

De Haven, who was engaged in the survey of the reef. We were told, also, that Kuria and Nononti were similar in having the reef elevated, though to a less extent. It would hence appear that the elevations in the group increase to the northward.

Marakei, to the north of Apaiang, is wooded throughout. We sailed around it without landing, and can only say that it has probably been uplifted like the islands south. *Makin*, the northernmost island, presented in the distant view no certain evidence of elevation.

The elevation of the Kingsmills accounts for the long continuity of the wooded lines of land, an unusual fact, considering the size of the islands. The amount of fresh water obtained from springs is also uncommon (p. 241).

l. The Marshall and *Caroline Islands.*—The facts in reference to the islands of these groups are not yet fully known. The very small amount of wooded land on the Pescadores inclines us to suspect rather a subsidence than an elevation; and the same fact might be gathered, with regard to some of the islands south, from the charts of Kotzebue and Kruesenstern. But McAskill's, as stated on page 261, is an elevated coral island, having a height of 100 feet.

m. Ladrones.—The seventeen islands which constitute this group may all have undergone elevations within a recent period, but owing to the absence of coral from the northern, we have evidence only with regard to the more southern.

Guam, according to Quoy and Gaymard, has coral rock upon its hills more than *six hundred* feet (one hundred toises) above the sea.

Rota, the next island north, afforded these authors similar facts, indicating the same amount of elevation.

n. Pelews and neighbouring Islands.—The island *Feis*, three hundred miles south-west of Guam, is stated by Darwin, on the authority of Lutke, to be of coral, and *ninety* feet high. *Mackenzie* Island, seventy-five miles south of Feis, is a low atoll, as ascertained by the Expedition. No evidences of elevation are known to occur at the Pelews.

o. Melanesian Islands.—Among the New Hebrides, New Caledonia, Salomon Islands, the evidences of elevation have not yet been examined.

The details given on the preceding pages are here presented in a tabular form.

		FEET.
Paumotu Archipelago,	Honden,	2 or 3
,, ,,	Clermont Tonnerre	2 or 3
,, ,,	Nairsa or Dean's,	6
,, ,,	Elizabeth,	80
,, ,,	Metia or Aurora,	250
,, ,,	Ducie's,	1 or 2
Tahitian Group,	Tahiti,	0?
,, ,,	Bolabola,	?
Hervey and Rurutu Groups,	Atiu,	12?
,, ,, ,, ,,	Mauke,	somewhat elevated.
,, ,, ,, ,,	Mitiaro, ,,	,,
,, ,, ,, ,,	Mangaia,	300
,, ,, ,, ,,	Rurutu	150
,, ,, ,, ,,	Remaining Islands,	0?
Tongan Group,	Eua,	300?
,, ,,	Tongatabu,	50 to 60
,, ,,	Namuka and the Hapaii,	25
,, ,,	Vavau,	100
Savage Island,		100
Samoan or Navigator Islands,		0
North of Samoa,	Swain's,	2 or 3
,, ,, ,,	Fakaafo, or Bowditch,	3
,, ,, ,,	Oatafu, or Duke of York's,	2 or 3
Scattered Equatorial Islands,	Washington,	2 or 3?
,, ,, ,,	Christmas,	?
,, ,, ,,	Jarvis's,	8 or 10
,, ,, ,,	Malden's,	25 or 30
,, ,, ,,	Starbuck's,	?
,, ,, ,,	Penrhyn's,	35
,, ,, ,,	Flint's and Staver's,	?
,, ,, ,,	Baker's,	5 or 6
,, ,, ,,	Howland's,	?
,, ,, ,,	Phœnix and McKean's,	0
,, ,, ,,	Enderbury's,	2 or 3?
,, ,, ,,	Newmarket,	6 or 8?
,, ,, ,,	Gardner's, Hull's, Sydney, Birnie's,	0?

		FEET.
Feejee Islands,	Viti Levu and Vanua Levu, Ovalau,	5 or 6
	Eastern Islands,	0?
North of Feejees,	Horne, Wallis, Depeyster,	0?
,, ,,	Ellice	5 or 6
Sandwich Islands,	Kauai,	1 or 2
,, ,,	Oahu,	25 or 30
,, ,,	Molokai	300
,, ,,	Maui,	12
Gilbert Islands,	Taputeuea,	2.or 3
,, ,,	Nononti, Kuria, Maiana and Tarawa,	3 or more.
,, ,,	Apamama,	5
,, ,,	Apaiang or Charlotte,	6 or 7
,, ,,	Marakei,	3 or more.
,, ,,	Makin,	?
Carolines,	McAskill's,	60
Ladrones,	Guam,	600
,,	Rota,	600
Feis,		90
Pelews,		0?
New Hebrides, New Caledonia, Salomon Islands,		none ascertained.

Several deductions are at once obvious :—

1. That the elevations have taken place in all parts of the ocean.

2. That they have in some instances affected single islands, and not those adjoining. Metia is 250 feet high, and yet the other Paumotus in that part of the archipelago, and also the Tahitian Islands, have been but little, or not at all, elevated.

3. That the amount is often very unequal in adjacent islands.

4. That in a few instances the change has been experienced by a whole group or chain of islands. The Gilbert Group is an instance, and the rise appears to increase from the southernmost island to Apaiang, and then to diminish again to the other extremity.

The Feejees may be an example of a rise at the west side of a group, and possibly a subsidence on the east, while a little farther east, the Tonga Islands constitute another extended

area of elevation. We observe that while the Samoan Islands afford no evidences of elevation, the Tonga Islands on the south have been raised, and also the Fakaafo Group and others on the north.

We cannot, therefore, distinguish any evidence that a general rise is, or has been, in progress; yet some large areas appear to have been simultaneously affected, although the action has generally been isolated. Metia and Elizabeth Island may have risen abruptly; but the changes of level in the Feejees and the Friendly Islands appear to have taken place by gradual action.

CHAPTER VI.

GEOLOGICAL CONCLUSIONS.

THE geological bearing of the facts that have been detailed in the preceding pages may have been already perceived by our readers. A brief review of the points of more special interest may serve as a convenient recapitulation of the subject.

I. FORMATION OF LIMESTONES.

Coral reefs are beds of limestone made of corals, with the help of shells. The mode of formation is essentially the same, whichever of the two kinds of organic products, corals or shells, predominate; although in one case the bed would be called coral limestone, and in the other, shell limestone.

The reefs illustrate two different modes of origin of such beds: (1), by undisturbed growth, with only additions of fine material to fill up the intervals; (2), by the grinding of the corals, &c., to fragments, sand, or mud, through the agency of the waves.

Beds made by the former method have many open spaces between the grouped masses or branches, and could not be turned into a solid layer of limestone if situated too deep in the ocean to feel sensibly the movement of the waves,—unless Rhizopods, or minute shells of some kinds, multiplied so rapidly over the same sea-bottom as to fill up the interstices.

There is no reason to believe that such aid from shells or Rhizopods is consistent with the grouping of living corals thickly enough to form reefs.

The other kind of limestone beds referred to, where unmixed with the former, grow up in compact layers to the surface, as a necessary consequence of wave-action; and limestones are made in such regions, instead of sandstones and shales, because the material exposed to degradation is corals and shells, instead of common rocks.

The facts show that there are formed about coral-reefs, in indefinite amount, all the ordinary products of degradation by wave-action—fragments large and small, down to sand, and even mud. With such an agent as the ocean's waves, driven often by the storm, so powerful and so persistent at lifting, rending, grinding, and transporting, it is of little account, at least about outer reefs, that some coral stems or masses are first weakened below by the boring sponge or mollusk; and neither fish, nor holothurian, nor alcyonoid is needed, in order to keep up the supply of particles for sand or mud-beds. In accordance with these facts, the reef-formations illustrate that not only coral conglomerates, or *coral rag*, may be made of corals, but also the very finest and most compact unfossiliferous limestones; that fine compact limestone, as flint-like in fracture as any of Silurian time, is one of the most common of coral-reef rocks, and is nothing but consolidated mud, or fine sand, of coral origin.

The elevated portion of the island of Matea, which consists largely of this kind of white, compact, coral-made limestone, appears to correspond to the interior of the original lagoon of the island; it exemplifies the kind of rock-making which is going forward in most coral-island lagoons. In archipelagos like that of the Feejees, where the reef channels are very broad, there is an opportunity for the formation of very large areas of this compact white limestone, and also for others of impure or argillaceous limestones.

Besides the kinds of coral-rocks above mentioned, there are also the *Beach* and *Drift Sand-rocks*, which are accumulated

and consolidated above low-tide level. These formations illustrate one common mode of origin of *oölitic* limestones. They also afford numerous examples of the formation of coarse and fine conglomerates consisting of beach pebbles—these pebbles being either worn corals, or shells, or sometimes of other kinds, if other rocks are at hand.

The uniform slope of the beach sand-rock, and oölite, and the mixed stratification of the drift sand-rock, are identical respectively with those of beach and drift-sand deposits in other regions.

II. BEDS OF LIMESTONE WITH LIVING MARGINS.

The coral reef as it lies at the water's level is in fact a bed of limestone with living margins; and the living part furnishes material for its horizontal extension outward, and also, if a slow subsidence is in progress, for its increase upward. It illustrates an ordinary mode of formation of coral, or of shell, limestone, whatever the age.

III. MAKING OF THICK STRATA OF LIMESTONE.

The coral reef-rock has been shown to have in some cases a thickness of at least 2,000 feet (page 126). The reefs are, therefore, examples of great limestone strata, nearly as remarkable in this respect as the largest of ancient times.

IV. SUBSIDENCE ESSENTIAL TO THE MAKING OF THICK STRATA.

The coral island reef-rock has been shown to depend for its thickness on a slowly progressing subsidence (p. 221). This is the only method by which any thick stratum of limestone could be made out of a single set of species, for all such species have a narrow range in depth; and the only way, from any succession of species, if those species are alike in range of depth.

In the case of existing coral reefs, there is yet no evidence that the species of the lower beds differ from those of the top.

There is also no evidence, in any part of any ocean, that there is a set of cold-water corals fitted to commence a reef in deep water and build it up to such a level that another set of species may take it and carry it up higher; the facts thus far gathered are all opposed to such an idea. Should it be hereafter proved that the corals of the inferior beds differ in species from those now existing, it will probably be found that the predecessors of those now living were also shallow-water species; so that the subsidence in any case was necessary.

V. DEEP-SEA LIMESTONES SELDOM IF EVER MADE FROM CORAL ISLAND OR REEF DEBRIS.

This point has been discussed on pages 114, 173. The facts show that the sediment or débris from a shore is almost wholly thrown back by the waves against the land where it originated, or over its submerged part in the shallow waters, and that it is not transported away to make deep-sea formations.

The facts have also a wider bearing, for they teach that lands separated by a range of deep ocean cannot supply one another with material for rocks. The existence of an Atlantic ocean continent—an Atlantis—has sometimes been assumed in order to make it a source of the mud, sand and gravel, out of which the thick sedimentary formations of the Appalachian region of North America were made. But if this Atlantis were a reality, there would still have been needed, in addition to the presence of such an ocean continent, a set of freight-carriers that could beat off the waves from their accustomed work, and push aside the ordinary oceanic currents; or else Atlantis would get back all its own dirt.

VI. ABSENCE OF FOSSILS FROM LIMESTONE STRATA.

Absence of fossils has been mentioned as a frequent characteristic of the fine compact coral reef-rock, and also of the beach and drift sand-rock or oölite (pp. 122, 158). The rocks are formed at the sea-level, and in the midst of abundant life,

and yet trituration by the action of the waves and winds has in many places reduced all to the finest material, so that an embedded shell is seldom to be found in the beach or drift oölite, and rarely too in much of the fine-grained coral reef-rock.

The lagoon basin appears to be eminently the place for making these non-fossiliferous limestones. This is the case in two widely different conditions: *first*, over the portions that are below the coral-growing depths, which are sometimes of great area; and *second*, in lagoons that have become so small and shallow that corals and large shells have all disappeared, and the trituration is of the finest kind, producing calcareous mud; such lagoons being properly in a marsh condition. These last appear to illustrate on a small scale the conditions under which many of the ancient non-fossiliferous, or sparingly fossiliferous, limestones were formed.

VII. THE WIDE RANGE OF THE OLDER LIMESTONES NOT EXEMPLIFIED AMONG MODERN CORAL-REEF FORMATIONS.

Coral-reefs, though they may stretch along a coast for scores of miles, are seldom a single mile in width at the surface; and if elevated above the sea, they would stand as broad ramparts separated by passages mostly 20 to 200 feet deep, and often of great width. The substratum, however, is, in general, continuous coral-rock; and if these more elevated parts were removed by any process, after an elevation, they would leave a nearly level area of coral limestone often as extensive as the whole reef-grounds. This is at once seen from the map of the islands of the Gilbert Group (p. 132), or that of the Feejees. In an island like Dean's, one of the Paumotus, these reef-grounds are 1,000 square miles in extent.

But the most extensive reef-grounds of the oceans are after all of small breadth compared with many of the ancient limestones of the continents; and the reef-rocks also are peculiar in their very abrupt limits, the margins sometimes descending at a steep angle a thousand feet or more. These differences

between the new and the old arise in part from the fact that the coral reefs of the present era are made about small oceanic lands, or along the edges of the continents, while the limestones of ancient time were gradually formed over the broad surface of a continent as it lay slightly submerged.

The Abrolhos reefs of the Brazilian coast, described on page 111, illustrate one of the methods by which the coral banks extend and finally coalesce into beds of wide extent; but these are small compared with the great limestones of early time, and owe their slight approximation to them as regards extent to the wide range of shallow waters there afforded. These Abrolhos reefs differ from most limestone beds also in being formed largely of the corals in the position of growth.

The tendency of modern reefs to grow up to the surface in narrow banks, separated by channels, appears to be unlike anything we discover in the old rocks; and it seems to be an unavoidable result of growth in the sea, where the waves pile up barriers, and the currents make, and keep open, channels. The case of the Australian and Feejee reefs are good examples. It is possible that such barriers may often have existed in ancient time, and have disappeared through subsequent denudation of the surface. But may not the difference between the great even layers of the continental formations and those of a coral island have proceeded from the difference in the depth of the seas? Over the great shallow continental seas where the limestones were in progress, the waves may have generally been feeble, and therefore there may have been a less tendency to form narrow barriers and deep intervening channels.

The marsh condition of a drying-up lagoon with its forming limestones has been compared above with that under which ancient unfossiliferous limestones were made. The narrow limits of the former make the comparison unsatisfactory; for, in the coral island, coarsely fossiliferous beds are all the while forming about the exterior of the island, but a few miles at the most from the lagoon-marsh; while the ancient limestones retain their unfossiliferous character often through many thousands of square miles. Still, the above-mentioned difference

between the continental sea and the existing deep oceans may perhaps account for the diversity of results.

VIII. CONSOLIDATION OF CORAL ROCKS.

All true coral-reef rocks are examples of the consolidation of material mainly of coral origin—either mud, sands, fragments, or standing corals, the last with mud or sands intermixed—by (1), an under-water process; (2), at the ordinary temperature; and they exemplify the mode in which all other submarine limestones of organic origin have been consolidated. The process appears to depend on the presence (proved by chemical analysis) of carbonic acid in the sea-waters that bathe and penetrate the sands. This carbonic acid is derived from three sources: from (1), the rains which wash it down from the atmosphere; (2) the respiration of all the animal life in the waters, even down to the simplest and minutest; and (3) the decomposition of all vegetable or animal débris in the waters or diffused through the sand or mud. This gas is set free, therefore, just where it is needed for the work, and is always ready to perform its part in the process of consolidation. It enables the water to take up carbonate of lime from the grains of the mass to be solidified, or from outside sources; and then the deposition of the same among the grains through their attractions produces the cementation.

The beach and drift sand-rocks or oölites are different from the reef-rock in being superficial deposits. The carbonic acid of the waters performs the same part as in the latter; but with these, there is alternate wetting and drying during the ebb and flow of the tides and the succession of gales and quiet winds. By this means the grains become incrusted, and every new wetting and drying adds a new layer to the surface of each; and thus the oölitic structure is produced. Facts are mentioned on page 122 of pebbles of volcanic or basaltic rocks, lying loose on a seashore, becoming incrusted in this way with a milky layer; and of basaltic conglomerates being made by the same means, the carbonate of lime being added until all

the intervals between the stones were filled up and the whole made solid; and of an amygdaloidal volcanic rock on a coast having derived its little calcareous kernels or amygdules from the same source. The following additional facts are cited from Mr. Darwin's Journal (p. 588):—

"Lieutenant Evans informs me that during the six years he has resided on this island (Ascension) he has always observed that in the months of October and November, when the sand [of a calcareous beach] commences travelling toward the south-west, the rocks which are situated at the end of the long beach become coated by a white, thick, and very hard calcareous layer. I saw portions of this remarkable deposit, which had been protected by an accumulation of sand. In the year 1831 it was much thicker than during any other period. It would appear that the water charged with calcareous matter, by the disturbance of a vast mass of calcareous particles only partially cemented together, deposits this substance on the first rocks against which it impinges. But the most singular circumstance is that in the course of a couple of months this layer is either abraded or redissolved, so that after that period it entirely disappears. It is curious thus to trace the origin of a periodical incrustation, on certain isolated rocks, to the motion of the earth with relation to the sun; for this determines the atmospheric currents which give direction to the swell of the ocean, and this again the arrangement of the sea-beach, and this again the quantity of calcareous matter held in solution by the waters of the neighbouring sea."

Mr. Darwin, speaking of a large beach of calcareous sand, composed of comminuted and rounded fragments of shells and corals at Ascension, says, "The lower part of this, from the percolation of water containing calcareous matter in solution, soon becomes consolidated, and is used as a building-stone; but some of the layers are too hard for fracture, and, when struck by the hammer, ring like flint."

The surface of hills of drift sand-rock often has small depressions that are coated with a smooth, solid crust, as already explained.

IX. FORMATION OF DOLOMITE, OR MAGNESIAN CARBONATE OF LIME.

Analyses of the coral limestone of the elevated coral island Matea, by Prof. B. Silliman, junr., have determined the singular fact that, although the corals themselves contain very little carbonate of magnesia, magnesia is largely present in some specimens of the rock. The rock is hard (H. = 4), and splintery in fracture, with a specific gravity 2·690. It affords on analysis, 38·07 per cent. carbonate of magnesia, and hence, only 61·93 of carbonate of lime.

Another specimen from the same island, having the specific gravity 2·646, afforded 5·29 per cent. of carbonate of magnesia.

The former was a compact homogeneous specimen, and the latter was partly fragmentary. Recent examinations of coral sand and coral mud from the islands give no different composition as regards the magnesia from that for corals, which, as the analyses on page 75 show, contain very little or no magnesia. The coral sand from the Straits of Balabac, afforded Prof. Silliman carbonate of lime 98·26, carbonate of magnesia 1·38, alumina 0·24, phosphoric acid and silica *a trace.*

This introduction of magnesia into the consolidating under-water coral sand or mud has apparently taken place (1) in sea-waters at the ordinary temperature; and (2) without the agency of any mineral waters except the ocean. But the sand or mud may have been that of a contracting and evaporating lagoon, in which the magnesian and other salts of the ocean were in a concentrated state. It has been already observed (p. 300), that this was probably the actual condition of the elevated portion of the island of Matea, everything about it looking as if it corresponded to the lagoon part of the old atoll; and also that the idea of the existence of mineral springs there has no support in known facts.

X. FORMATION OF CHALK.

The formation of chalk from coral is known to be exemplified at only one spot among the reefs of the Pacific. The coral mud often looks as if it might be a fit material for its production; moreover, when simply dried, it has much the appearance of chalk, a fact pointed out by Lieutenant Nelson in his Memoir on the Bermudas (1834), and also by Mr. Darwin, and suggested to the author by the mud in the lagoon of Honden Island. Still this does not explain the origin of chalk; for, under all ordinary circumstances, this mud solidifies into compact limestone instead of chalk, a result which would naturally be expected. What condition then is necessary to vary the result, and set aside the ordinary process?

The only locality of chalk among the reefs of the Pacific, referred to above, was not found on any of the coral islands, but in the elevated reef of Oahu, near Honolulu, of which reef it forms a constituent part. It is twenty or thirty feet in extent, and eight or ten feet deep. The rock could not be distinguished from much of the chalk of England; it is equally fine and even in its texture, as earthy in its fracture, and so soft as to be used on the blackboard in the native schools. Some imbedded shells look precisely like chalk fossils. It contained, according to Professor Silliman, 92·80 per cent. of carbonate of lime, 2·38 of carbonate of magnesia, besides some alumina, oxide of iron, silica, &c.

The locality is situated on the shores, just above high-tide level, near the foot of Diamond Hill. This hill is an extinct tufa cone, nearly seven hundred feet in height, rising from the water's edge, and in its origin it must have been partly submarine. It is one of the lateral cones of eastern Oahu, and was thrown up at the time of an eruption through a fissure, the lavas of which appear at the base. There was some coral on the shores when the eruption took place, as is evident from imbedded fragments in the tufa; but the reef containing the chalk appeared to have been subsequent in formation, and

afforded no certain proof of any connection between the fires of the mountain and the formation of the chalk.

The fine earthy texture of the material is evidence that the deposit was not a *subaerial* seashore accumulation, since only sandstones and conglomerates, with rare instances of more compact rocks, are thus formed. Sand-rock-making is the peculiar prerogative, the world over, of shores exposed to waves, or strong currents, either of marine or fresh water. We should infer, therefore, that the accumulation was produced either in a confined area, into which the fine material from a beach may have been washed, or on the shore of a shallow, quiet sea; in other words, under the same conditions nearly as are required to produce the calcareous mud of the coral island. But, although the agency of fire in the result cannot be proved, it is by no means improbable, from the position of the bed of chalk, that there may have been a hot spring at the spot occupied by it. That there were some peculiar circumstances distinguishing this from other parts of the reefs is evident.

This, if a true conclusion, is to be taken, however, only as one method by which chalk may be made. For there is no reason to suppose that the chalk of the Chalk-formation has been subjected to heat. On the contrary, it is now well ascertained that it is of cold-water origin, even to its flints, and that it is made up largely of minute foraminifers, the shells of Rhizopods. Professor Bailey found under his microscope no traces of foraminifers, or of anything distinctly organic, in the Oahu chalk.

XI. RATE OF INCREASE OF LIMESTONE FORMATIONS.

On page 212 it is shown that coral-reef limestones are of slow formation, the rate of increase in thickness, where all is most favourable, not exceeding perhaps a sixteenth of an inch a year, or five feet in a thousand years. And yet such limestones probably form at a more rapid rate than those made of shells, because the animals are to a larger extent calcareous, or

make proportionally larger calcareous secretions; and in addition they have the property of rapid multiplication by budding. The mollusks that grow and multiply most rapidly, and have proportionally the largest shells, are the Lamellibranchs, or bivalves, among which the oyster is a famous example; and the Brachiopods were once the full equals of the ordinary bivalves. Large banks of bivalves seldom occur in regions of corals, the species there being to a great extent Gasteropods (or univalves); and hence the contributions of shells to coral reefs from mollusks are small compared with the extent of the beds which, by themselves, they make on other coasts. The coral seas of Florida nowhere have shore shell-beds like those of St. Augustine in Northern Florida outside of the coral-reef seas. There is reason for this in the fact that those bivalves that grow in large banks live in beds of ordinary sand or mud, such as reef-regions do not generally supply.

XII. LIMESTONE CAVERNS.

The elevated coral limestone, although in general a hard and compact rock, abounds in caverns. They may be due in part to open spaces, or regions of loose texture, in or between the strata. But in most cases they are a result of solution and erosion by the fresh waters of the land, or the waves and currents of the ocean, subsequent to the elevation.

On the island of Metia, many caverns open outward in the coral limestone cliff, and in some were large stalactites, as stated on page 157.

In the raised coral rock of Oahu (p. 290) there are several long winding horizontal chambers, some of which are the sources of subterranean streams that open out on the shores between the layers of the rock, or from the mouths of caverns. These running waters, and others trickling from above, are obviously the eroding agents that have made the caves.

As briefly remarked on page 157, caverns are still more remarkable on the island of Atiu, on which the coral reef-rock stands at about the same height above the sea as on Oahu.

The Rev. John Williams states that there are seven or eight of large extent on the island. Into one he entered by a descent of twenty feet, and wandered a mile in one only of its branches without finding an end "to its interminable windings." He says, "Innumerable openings presented themselves on all sides as we passed along, many of which appeared to be equal in height, beauty, and extent to the one we were following. The roof, a stratum of coral rock fifteen feet thick, was supported by massy and superb stalactitic columns, besides being thickly hung with stalactites from an inch to many feet in length; some of these pendents were just ready to unite themselves to the floor, or to a stalagmitic column rising from it. Many chambers were passed through whose fretwork ceilings and columns of stalactites sparkled brilliantly, amid the darkness, with the reflected light of our torches. The effect was produced not so much by single objects, or groups of them, as by the amplitude, the depth, and the complications of this subterranean world."

Other similar caves exist on the neighbouring island of Mauke.

The Bermudas are also noted for their caverns. The coral-made land here stands in some places 260 feet above the sea. Lieutenant Nelson speaks of the caverns as large and beautiful —one of them "a perfect bijou."

These are examples of the comparatively rapid formation of caverns. The waters which run or percolate through them must be charged with carbonic acid to accomplish such work, and yet they have no source for this ingredient except the atmosphere, animal respiration, and vegetable and animal decomposition in the soil. The flutings and stalactitic incrustations of a precipice facing the sea must depend on the former alone, with the aid perhaps of the spray from the sea brought over the reef by storms.

XIII. OCEANIC TEMPERATURE.

Facts seem to indicate—though perhaps not sufficient to demonstrate—that the Gulf Stream has had, from the Jurassic

period in Geological history onward, the same kind of influence on the temperature of the North Atlantic Ocean which it now has.

The existence of a coral reef made out of corals of the Astræa tribe and others, during part of the Oölitic era (middle Jurassic), in England, as far north as the parallel of 52° to 55° is strong evidence that the isocryme of 68° F., the coral-reef boundary, extended then even to that high latitude; for species of the Astræa tribe are now confined to coral-reef seas (p. 84). This isocryme now reaches along the course of the Gulf Stream to a point just north of the Bermudas, near 33° N.; and 55° is 22° beyond this.

There are no marine fossils in any rocks of that period on the American side of the Atlantic, so that facts fail for definitely locating the *western* terminus of this oölitic isocryme of 68° F. But it is highly improbable that the whole ocean across, on, or near the parallel of 55° N., should have had, as the mean temperature for the coldest month of the year, one so high as 68° F.; the present average position of the isocryme of 68° F., through the middle of the two oceans, the Pacific and Atlantic, is near the parallel of 27° or 28°, or one-half nearer the equator than the parallel of 55°. It is difficult to account for an oceanic temperature high enough to give England's seas 68° F. as the average for the coldest winter month, even supposing the Gulf Stream to have aided; but it is vastly more difficult if no such north-eastward current existed and the high temperature extended equably so far from the equator. The probability is therefore strong that the existence of coral reefs in the Oölitic era in England was owing to the extension, by the aid of the Gulf Stream, of the isocryme of 68° more than 30° in latitude (and over 3,000 miles in distance) beyond its present most extra-tropical position, just outside of the Bermudas; in other words, that the whole ocean was just enough warmer to allow this oceanic current (part of the great water-circulation of the globe) to bear the heat required for corals as far north as northern England.

The present isocryme of 44° F., as drawn on the chart of

the world accompanying this volume, has approximately the course which that of 68° F. probably had in Oölitic times. It should have a little less northing, and the loop to the north should lean more to the eastward. The latter would have been a consequence of the submerged condition at the time of most of the European continent.

The ocean's waters seem to have cooled somewhat before the next period—the Cretaceous—began, since evidence fails of any Cretaceous coral reefs in the British seas; but such reefs prevailed then in central and southern Europe, so that the amount of cooling in the interval since the Oölitic era had not been large; and as late as the Miocene Tertiary there were reef corals in the seas of Northern Italy, above latitude 45° N., or that of Montreal, in Canada.

The absence from the American coast of the Atlantic of any coral reefs in the Cretaceous beds, and of any reef corals, seem to show that the oceanic temperature off this coast was not favourable for such corals; and if so, then the line of 68° F. extended at least 20° farther north on the European side of the ocean than on the Atlantic—an inequality to be accounted for in part by the existence of the Gulf Stream.[1] But, in addition, the whole range of life in the European Cretaceous, and its vastly greater variety of species, leave no doubt as to the higher temperature of the ocean along its European border; so that the idea of a Cretaceous Gulf Stream must be accepted. And that of a Tertiary is demonstrated by similar facts.

If the Gulf Stream had its present position and force in Oölitic, Cretaceous, and Tertiary times, then the ocean had, throughout these eras, its present extension and oceanic character; and, further, no barrier of land extended across from South America to the Canaries and Africa, dividing the South from the North Atlantic, but all was one great ocean. Such a barrier would not annul entirely the flow of the Gulf Stream; yet the North Atlantic is so small an ocean that, if left to itself, its system of currents would be very feeble.

[1] The influence of oceanic currents on the isothermal lines of the ocean is briefly stated on pages 255, 256.

XIV. THE OCEANIC CORAL ISLAND: SUBSIDENCE.

Coral islands have been shown to be literally monuments erected over departed lands; and, through the evidence from such records, it is discovered that the Pacific has its deep-water mountain chains, or lines of volcanic summits, not merely hundreds, but thousands of miles in length. Some of the ranges of high islands are proved by such records to have an under-water prolongation, longer than that above water: the Hawaian Islands for example, which have a length of only four hundred miles from Hawaii to Kauai, and five hundred and thirty to Bird Island, the western rocky islet of the group, stretch on westward, as the coral registers show, even to a distance of two thousand miles from Hawaii, or, as far as from New York to Salt Lake City; and how much farther is unknown, as the line of coral islands here passes the boundary of the coral-reef seas, or the region where coral records are possible.

Other ranges of submerged summits are shown to extend through the whole central Pacific, even where not a rocky peak remains above the surface: for all the coral islands from the eastern Paumotus to Wakes' Island, near long. 170° E. and lat. 19° N., north of the Ralick and Radack (or Marshall) groups, are in linear ranges; and they have, along with the equally linear ranges of high islands just south, a nearly uniform trend, curving into north-west and north-north-west at the western extremity. The coral islands consequently cap the summits of linear ranges of elevations, and all these linear ranges together constitute a grand chain of heights, the whole over five thousand miles in length. Thus, the coral islands are records of the earth's submarine orography, as well as of low changes of level in the ocean's bottom.

This coral-island subsidence is an example of one of the great secular movements of the earth's crust. The axis of the subsiding area—the position of which is stated on page 280, has a length of more than six thousand miles—equal to one quarter of the circumference of the globe; and the breadth,

reckoning only from the Sandwich Islands to the Friendly Group (or to Tongatabu) is over twenty-five hundred miles, thus equalling the width of the North American continent. A movement of such extent, involving so large a part of the earth's crust, could not have been a local change of level, but one in which the whole sphere was concerned as a unit; for all parts, whether participating or not, must have in some way been in sympathy with it.

This subsidence was in progress, in all probability, during the Glacial era, the thickness of the reefs proving that in their origin they run back through a very long age, if not also into the Tertiary. It was a downward movement for the tropical Pacific, and perhaps for the warmer latitudes of all the oceanic areas, while the more northern continental lands, or at least those of North America, were making their *upward* movement, preparatory to, or during that era of ice.

The subsidence connected with the origin of coral islands and barrier reefs in the Pacific has been shown (p. 281) to have amounted to several thousands of feet, perhaps full ten thousand. And it may be here repeated, that, although this sounds large, the change of level is not greater than the *elevation* which the Rocky Mountains, Andes, Alps, and Himalayas have each experienced since the close of the Cretaceous era, or the early Tertiary; and perhaps it does not exceed the upward bulging in the Glacial era of part of northern North America.[1]

The northern continental upward movements which introduced the Glacial era, carrying the Arctic far toward the Tropics, may have been a balance to the *downward* oceanic movements that resulted in the formation of the Pacific atolls. While the crust was arching upward over the former (not rising into mountains, but simply arching upward) it may

[1] The arguments which have seemed to favour the view that the portions of North America in the higher latitudes, and probably also in the corresponding parts of the other continents, were above their present level, are briefly presented by the author in his "Manual of Geology," and also, recently, in the *American Journal of Science*, third series, volume v.

have been bending downward over the vast central area of the great ocean.

The changes which took place, cotemporaneously, in the Atlantic tropics are very imperfectly recorded. The Bahamas show by their form and position that they cover a submerged land of large area stretching over six hundred miles from north-west to south-east. The long line of reefs and the Florida Keys, trending far away from the land of southern Florida, are evidence that this Florida region participated in the downward movement, though to a less extent than the Bahamas. Again, the islands of the West Indies diminish in size to the eastward, being quite small, in a long line that looks out upon the blank ocean, just as if the subsidence increased in that direction. Finally, the Atlantic beyond is water only, as if it had been made a blank by the sinking of its lands.

Thus the size of the islands, as well as the existence of coral banks, and also the blankness of the ocean's surface, all appear to bear evidence to a great subsidence.

The peninsula of Florida, Cuba, and the Bahamas look, as they lie together, as if all were once part of a greater Florida or south-eastern prolongation of the continent. The north-western and south-western trends, characterizing the great features of the American continent, run through the whole like a warp-and-woof structure, binding them together in one system; the former trend, the north-west, existing in Florida and the Bahamas, and the main line of Cuba; and the latter course, the west-southwest, in cross lines of islands in the Bahamas (one at the north extremity, another in the line of Nassau, and others to the south-east), in the high lands of north-western and south-eastern Cuba, and in the Florida line of reefs, and even farther, in a submerged ridge between Florida and Cuba. This combination of the two continental trends shows that the lands are one in system, if they were never one in continuous dry land.

We cannot here infer that there was a *regular* increase of subsidence from Florida eastward, or that Florida and Cuba

participated in it equally with the intermediate or adjoining seas; for the facts in the Pacific have shown that the subsiding oceanic area had its nearly parallel bands of greater and less subsidence, that areas of greatest sinking alternated with others of less, as explained on page 279; and that the groups of high islands are along the bands of least sinking. So in the Atlantic, the subsidence was probably much greater between Florida and Cuba than in the peninsula of Florida itself; and greater along the Caribbean Sea parallel with Cuba, as well as along the Bahama reefs, than in Cuba.

The position of the lonely Bermuda atoll confirms these deductions. Its solitary state is reason for suspecting that great changes have taken place about it; for it is not natural for islands to be alone. The tongue of warm water due to the Gulf Stream, in which the Bermudas lie, is narrow, and an island a hundred miles or more distant to the northeast-by-east, or in the line of its trend (p. 183), if experiencing the same subsidence that made the Bermuda land an atoll, would have disappeared without a coral monument to bear record to its former existence. Twenty miles to the southwest-by-west from the Bermudas there are two submerged banks, twenty to forty-seven fathoms under water, showing that the Bermudas are not completely alone, and demonstrating that they cover a summit in a range of heights; and it may have been a long range. This suggestion as to the former extent of the Bermuda Group has been recently sustained by the observations of Mr. J. Matthew Jones, cited on page 185.

In the Indian Ocean, again, there is evidence that the coral-island subsidence was one that affected the oceanic area more than the adjoining borders of the continent, and most, the central parts of the ocean. For, in the first place, the archipelago of the Maldives narrows and deepens to the southward (p. 152). Further, the large Chagos Group, lying to the south of the Maldives, contains but very little dry land in any of its extensive reefs, while some of them, including the Great Chagos Bank, are sunken atolls. Again, still other large reefs nearly bare, lie to the south-west of the Chagos Group; while

Keeling's is another outlying atoll south-west of southern Sumatra and far out toward mid-ocean.

The probability is, therefore, that both the central Atlantic and Indian Oceans were regions of this subsidence, like the central Pacific, and that the absence of islands over a large part of their interiors may be a consequence of it. A rate of sinking exceeding five feet in a thousand years (if the estimate on page 215 is right) would have buried islands and reefs together in the ocean; while, with a slower rate, the reefs might have kept themselves at the water's surface. So small may have been the difference of rate in the great movement that covered the Pacific with coral islands, but left the Indian Ocean a region of comparatively barren waters, with some "half-drowned" atolls, and the central Atlantic almost wholly a blank.

While thus seeming to prove that all the great oceans have their buried lands, we are far from establishing that these lands were oceanic continents. For as the author has elsewhere shown, the profoundest facts in the earth's history prove that the oceans have always been oceans. These lands in all probability were, for the most part, volcanic islands or summits of volcanic ranges, for of this nature are all the islands over the interior of either ocean that are not of coral origin.

The course of argument leads us to the belief that a very large number of islands, more than has been supposed, lie buried in the ocean. Coral islands give us the location of many of these lands: but still we know little of the extent to which the earth's ranges of heights, or at least of volcanic peaks, have disappeared through oceanic subsidence. Recent dredgings and soundings have proved that the bottom of the oceanic basin has little of the diversity of mountain chains and valleys that prevails over the continents; and, through this observation (and also by the discovery that some ancient types of animal life, supposed to have been long extinct, are perpetuated there), they have afforded new demonstration of the proposition, above stated, that *the oceans have always been oceans*. But while the facts do not imply the existence deep

in the ocean of many granitic mountain chains, they do teach that there are long ranges, or lines, of volcanic ridges and peaks, and some of these may be among the discoveries of future dredging expeditions. A range of deep-sea cones, or sunken volcanic islands, would be as interesting a discovery as a deep-sea sponge or coral, even if it should refuse, excepting perhaps a mere fragment, to come to the suface in the dredge.

We may also accept, with some confidence, the conclusion that atolls and barrier reefs originated in the same great balance-like movement of the earth's crust that gave elevation and cold, in the Glacial era, to high-latitude lands. If so, the tropics and the colder latitudes were performing their several works simultaneously in preparation for the coming era; and it is a gain to us in our contemplations, that we hence may balance the beauty and repose of the tropics, through all the progressing changes, against the prolonged scenes of glacial desolation that prevailed over large portions of the continents.

APPENDIX.

THE following brief explanations are here added for the benefit of the general reader.

I. GEOLOGICAL TIME.

The terms Paleozoic era, Oölitic period, and Glacial era or period, have been used in the preceding pages. The positions of these eras in geological history will be gathered from the following review of its principal divisions.

Geological history begins with what has been called *Azoic* time, *azoic* signifying the absence of all life. But the rocks supposed to be Azoic have been found to afford evidence of the existence of the simplest kinds of life during their formation; and the era they represent is, therefore, more correctly styled the *Archeozoic*, from the Greek for *beginning* and *life*.

The other grand subdivisions of geological time are as follows:

PALEOZOIC TIME (named from the Greek for *ancient life*), in the course of which the earliest Corals, Mollusks, Crustaceans, Insects, Fishes and Reptiles existed. It includes three Ages: (1), the *Silurian;* (2), the *Devonian*, or Age of Fishes; and (3), the *Carboniferous*, or Age of Coal-plants, when the most extensive beds of mineral coal of the world were originated.

2 MESOZOIC TIME, or that of *mediæval life*. It corresponds to the Age of Reptiles—being the era, not of the earliest reptiles, but that of their climax in number, size, and variety. This age is divided into three periods: first, or earliest, the Triassic; second, the Jurassic, to which the Oölitic era belongs; and, third, the Cretaceous, or that of the Chalk.

3. CENOZOIC TIME, or that of *recent life*, as the term signifies. It is modern in the aspect of its species, compared with the Mesozoic, and still more so compared with the Paleozoic. The highest and dominant species were *Mammals*, ending in Man.

Cenozoic time is divided into two Ages, the TERTIARY and the QUATERNARY. The Quaternary age, the last in the geological series, commences with the *Glacial* period, when, over Northern North America, vast quantities of stones, gravel and sand, were

transported by ice from the north, and spread over the surface down to the parallel of about 40°, and of finer material still farther south along the great valleys, extending in the Mississippi Valley, as Prof. E. W. Hilgard has shown, even to the Gulf of Mexico. The transportation was probably, for the most part, the work of a continental glacier, covering a large part of the continent north of 40°, and of the floods proceeding from its final melting. Europe also had, at the same time, its northern glacier, reaching down to the parallel of 50°, along which parallel the temperature is about the same as on the parallel of 40° in North America.

The Glacial period in North America was an era of greater continental elevation than now exists—at least for the glacial latitudes, that is, from the parallel of 40° northward. It was followed by the *Champlain* era, the era of a subsidence of the land below its present level, over the same northern regions, which subsidence was accompanied by a moderating of the climate, and a melting of the glacier. Next came the *Terrace* era, marked by the elevation of the continent toward, and finally to, its existing height, and a consequent making of terraces along river valleys, around lakes, and on many sea borders.

II. RADIATES.

Polyps have been described as constituting one of the grand divisions of *Radiates*.

Radiates are characterized by a radiate system of structure, apparent both externally and internally: in other words, they consist of different series of similar parts repeated around a vertical axis. In polyps the tentacles are thus repeated; so, also, the internal septa; the reproductive system; the eyes, where these exist; and so on through the structure. In order to make this distinctive feature of Radiates more intelligible, a few words are here presented on the other grand divisions of the Animal Kingdom, or the Sub-Kingdoms as they are called. The number of Sub-Kingdoms is five, as follows:

1. Sub-kingdom of VERTEBRATES.—This designation refers to a fundamental feature of the species,—the backbone or spinal column, consisting of a series of bones (sometimes cartilaginous only), articulated together, called, in the Latin language, *vertebræ*. In connection with this, they have a cavity above for the great nervous cord, and one below for the viscera. Here belong Mammals (or Man, Quadrupeds, Whales, and the like), Birds, Reptiles, Fishes. All other animals are *invertebrates*, that is, have no vertebral column.

2. Sub-kingdom of AUTICULATES—so named with reference to the fact that the body consists of a series of segments or joints, articulated together; and that all the legs, antennæ, and other appendages, are likewise jointed (articulated). The body has one

cavity containing both the viscera and the principal nervous cord, the latter situated below the alimentary canal. The species included are Insects, Spiders, Centipedes, Crustaceans (or Crabs, Lobsters, Shrimps and the like), and Worms.

3. Sub-kingdom of MOLLUSKS—or, as the name implies, species having soft fleshy bodies, which are characterized also by a simple bag-like structure, and by the absence of joints both from the body and all appendages. As in Articulates, similar organs are repeated on the right and left sides of a median plane, instead of around a central axis; but there is no succession of segments in the body, or of corresponding ganglia (nervous masses) in the nervous system; and, consequently, Mollusks have not that composite feature that characterizes and distinguishes Articulates. Examples are the Oyster, Clam, Snail, Cuttle-fish, and Bryozoans (mentioned on page 81). Many of the species have shells, as an external covering; but many also are without them.

4. Sub-kingdom of RADIATES, the subject of this note.

5. Sub-kingdom of PROTOZOANS, briefly described on a following page.

The division of Radiates is thus the lowest but one in the system of animal life, and its species are strikingly distinct from the higher kinds in the radiate arrangement of the parts within and without.

Radiates are of three Classes.

1st. *Polyps*, whose characters have already been stated (p. 3 and beyond).

2d. *Acalephs*, or Jelly-fishes, or Medusæ, as many of them are called. Acalephs are often nearly transparent and jelly-like in aspect, though not in consistence. They have sometimes the shape of a disk, convex above, or a hemisphere, or a bell-shaped spheroid, and vary in diameter from a fraction of an inch to three yards or more. Attached either to the margin, or to the under concave surface about the mouth, there are usually four tentacles or groups of tentacular appendages, or a continuous fringe of tentacles; or there are other tasselings beneath the pellucid body; and these organs, like the tentacles and some other parts of an Actinia, are furnished with myriads of lasso-cells. The whole structure is as completely radiate within and without as that of a Polyp; but there are radiating, and radiately branching, vessels passing outward from the stomach cavity instead of radiating compartments. Acalephs, or jelly-fishes, float in the ocean, usually with the mouth downward, moving ordinarily by the contraction and expansion of the sides of the body. Hydroids (p. 76) are sexless forms under one division of Acalephs; they are usually attached, and look like polyps.

3d. *Echinoderms*. Examples of this class are, *first*, the *star-fishes*, or *five-fingers*, whose bodies, although containing calcareous plates, are somewhat flexible, and ordinarily either five-rayed (fingered) or five-angled (but sometimes more than five):—*second* the *Echinus* or

sea-hedgehog, so called from the spines that stand out in all directions over the thin, but firm, hollow shell; *third*, the *Holothurians*, or *sea-slugs*, alluded to on page 129, whose bodies are long and flexible, and the exterior is a fleshy skin, usually thick, often with calcareous points or pieces in the skin, but not enough to interfere with its slug-like flexibility. There are also other lower kinds, which need not be here described.

In Polyps the number of similar radiate parts in the structure is typically a multiple either of *six* or of *four;* in Acalephs, of *four;* in Echinoderms, of *five*. Some variations occur under each of these divisions; but they may probably be regarded as modifications of the type by suppression in development, or the reverse.

The Echinoderms are the highest of Radiates. They show their superiority of rank in having more perfect nervous, digestive, and branchial systems, generally an anal opening to the alimentary canal instead of only a mouth, and a better organized mouth; also in the absence of lasso-cells, this provision of a stinging apparatus in the skin being a special attribute of inferiority. They have tentacles (under the form of suckers and also of branchiæ), but these organs are usually arranged along the body radiately with reference to the mouth or the opposite extremity of the animal; and the tentacular (or ambulacral) compartments alternate with others non-tentacular (inter-ambulacral). When the body is long, as in the Holothurians, the five ranges of tentacles extend along the sides of the body.

In many points, the Echinoderms are unlike Polyps; and yet the two are fundamentally similar in the radiate system at the basis of the structure; in the alternation of tentacular and non-tentacular compartments when both kinds exist; in the annular character of the nervous system—for, although the nervous ring is not complete either in Polyps or Acalephs, the isolated parts existing in these species are manifestly rudiments of the nervous ring of the Echinoderms; in the system of water-circulation, which in Polyps differs from that of Echinoderms only in being less perfect; and in other points which cannot here be dwelt upon.

To the more scientific reader a word is here added on the question whether Echinoderms are true Radiates. They have been separated from this sub-kingdom by some zoölogists on the ground of their having a better defined alimentary canal, with two extremities to it instead of only a mouth; also a more perfect nervous system and a more perfect aquiferous system; and their not being furnished with lasso-cells:—the Polyps and Acalephs being distinctively designated by such systematists *Cœlenterates*. But the organs, or arrangements, for the purposes of digestion, sensation, aeration, prehension, are only the means by which the animal sustains itself and does its work, while the type of structure is something fundamental to all these conditions of its exhibition. The fact of the radiate structure, and of the general homology in the several parts between the Echinoderms and other Radiates, is not affected by the

fact of the nutritive system having one or two open extremities, or by the perfection of the nervous or branchial systems, or by the condition of the general visceral cavity. Moreover some Echinoderms have *only one* opening to the alimentary cavity, while *some Acalephs have two*, like the highest Echinoderms, thus proving that such distinctions are of small importance alongside of system of structure. Again, the nervous system of Echinoderms, as already stated, is only the perfected state of the nervous system of some Polyps and Acalephs.

Echinoderms appear to differ strikingly from Polyps in having many tentacles from one tentacular compartment. But in Polyps, one compartment has occasionally, besides its one tentacle, a series of them; thus evincing the same fundamental idea in the structure of the two, and affording proof of their close relationship. The branchial rosette in a Holothurian looks quite peculiar; but Actiniæ that live, like most Holothurians, in the sand, have sometimes a similar branchial rosette, the crimped or finely divided appendages among the tentacles of such Actiniæ being true branchiæ, as Verrill has observed; and, further, such appendages have no compartment of their own, but grow out from one that bears its normal tentacle (page 19). The group of tentacles and branchial appendages in the Actinia constitute a rosette around the mouth wholly analogous to that of a Holothurian. This peculiarity is therefore confirmatory evidence that Polyps and Echinoderms are one in system of structure and alike Radiates.

III. PROTOZOANS.

Foraminifers, which include the Orbitolites (mentioned on page 121), the Globigerinæ (page 174), and also Sponges, are the secretions of Protozoans, just as ordinary corals are the secretions of Polyps.

Protozoans, the lowest and simplest of animals, show their simplicity in, *first*, their minuteness, the animals being mostly between a 100th and a 10,000th of an inch in length; *secondly*, in having no external organs or parts, excepting (1) a mouth, and (2) minute cilia or thread like processes; *thirdly*, in having no distinguishable digestive apparatus excepting a stomach; *fourthly*, in the fact that the stomach and mouth are sometimes wanting, or exist only when extemporized for the occasion. The species have, besides, a palpitating vesicle or vacuole within the body which appears to serve the purpose of a heart. Part of the so-called Infusoria are Protozoans.

In the lowest section of Protozoans—that of the *Rhizopods*—the animal has a spheroidal body, if of any particular shape, but is generally without a permanent mouth or stomach. It has the power of extending out portions of its protoplasmic body in the form of thread-like processes, and thence the name Rhizopod,

signifying *root-like feet*. Many of the species secrete shells, and although the shell of a single animal may not be larger than the point of an ordinary pin, it has pores or foramina through it which give exit to the thread-like processes; and the shells are therefore called *foraminifers*.

Rhizopods occur often as solitary animals; but generally, like polyps, they multiply by budding, and thus make groups of cells, some of the larger of which have the magnitude of a quarter of a head of a pin; of this nature are the Globigerinæ, and various other kinds, common over the bottom of the deep ocean, as well as in many shallow waters. A few form, through the budding process, disk-like or coin-shaped foraminifers, half an inch to an inch in diameter; and such are the *Orbitolites*, referred to, on page 121, as contributing largely to the coral reefs of the Australian seas, while common throughout the reef regions of the Pacific.

In one division of Rhizopods—that including the Globigerinæ and Orbitolites—the foraminifers are calcareous; in another, they consist of agglutinated sand; in another (that of the Polycystines) they are siliceous.

In another section of Protozoans called the *Flagellate Infusoria*, and including the Monad, there is a permanent mouth, and often a slender process (*flagellum*) which appears to serve the mouth by pushing in food. The animals are much more minute than the Rhizopods. To this section, as Prof. H. James Clark has shown, belong the sponges—a sponge being a compound group of these living infinitesimals produced by growth and budding.

A third division of Protozoans is that of the Vorticellæ and related forms. They have at top a circle or spiral of cilia, around a disk, in one part of which disk the mouth is situated. These beautiful species—occasionally large enough to be visible to the naked eye—often grow in clusters resembling somewhat those of the Hydroids and Bryozoans.

IV. NAMES OF SPECIES IN THE AUTHOR'S REPORT ON ZOÖPHYTES.

THE following catalogue contains the names that are now accepted for the species of Actinoid Coral Zoöphytes described in the Author's Report. The changes have chiefly resulted from the subdivision of the old genera. The catalogue has been prepared for this place by Prof. VERRILL, and the explanatory Notes have been added by him.

PAGE.	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
159.	Euphyllia pavonina	Flabellum pavoninum *Lesson.*
	,, anthophyllum	,, anthophyllum *E. & H.*
	,, spheniscus	,, spheniscus *E. & H.*
	,, rubra	,, rubrum *E. & H.*
	,, spinulosa	Desmophyllum spinulosum *Verrill.*
	,, glabrescens	unchanged.
	,, gracilis	,,
	,, aspera	Eusmilia aspera *E. & H.*
	,, aperta	,, fastigiata *E. & H.* (?)
	,, costata (p. 720)	,, costata *Verrill.*
	,, rugosa	unchanged.
	,, turgida	,,
	,, meandrina	Euphyllia fimbriata *E. & H.*
	,, sinuosa	Pterogyra sinuosa *E. & H.*
	,, cultrifera	,, cultrifera *E. & H.*
170.	Ctenophyllia pectinata (not of *Lam.*)	Pectinia Danæ *E. & H.*
	quadrata	,, quadrata *E. & H.*
	pachyphylla	,, pachyphylla *E. & H.*
	profunda	,, profunda *E. & H.*
174.	Mussa fastigiata	unchanged.
	,, carduus	,,
	,, angulosa	,,
	,, corymbosa	

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
174.	Mussa. cactus	unchanged.
	,, costata	,,
	,, sinuosa (not of *Ellis*)	Mussa tenuidentata *E. & H.*
	,, cytherea	unchanged.
	,, multilobata	,,
	,, cerebriformis	,,
	,, regalis	,,
	,, crispa (not of *Lam.*)	Mussa Indica *Verrill*, and Mussa radians *Verrill.*
	,, dipsacea	Isophyllia dipsacea *Verrill.*
	,, fragilis	,, fragilis *Verrill.*
	,, gyros	Colpophyllia gyrosa *E. & H.*
	,, recta	unchanged.
	,, nobilis	,,
189.	Manicina amarantum	Tracyphyllia amarantum *E. & H.*
	,, fissa	Colpophyllia.
	,, arealata [2]	Manicina areolata *Ehr.*
	,, meandrites	
	,, hispida	
	,, prærupta	
	,, dilatata	
195.	Tridacophyllia lactuca	unchanged.
196.	,, pæonia	,,
	,, manicina	,,
198.	Caulastræa furcata	,,
199.	,, distorta	,,
	,, undulata	,,
205.	Orbicella [3] radiata	Orbicella radiata *Dana.*
	,, argus	,, cavernosa *Verrill.*
	,, glaucopis	,, glaucopis *Dana.*
	,, patula	Acanthastræa patula *E. & H.*
	,, curta	Plesiastræa curta *E. & H.*
	,, rotulosa	Astræa rotulosa *Lam.*
	,, coronata	Plesiastræa coronata *E. & H.*
	,, hyades	Solenastræa hyades *Verrill.*
	,, excelsa	,, excelsa *Pourtales.*
	,, pleiades	,, pleiades *Verrill.*
	,, annularis	Orbicella annularis *Dana.*
	,, stellulata	,, stellulata *Dana.*
	,, stelligera	Plesiastræa stelligera *E. & H.*
	,, crispata	Ulastræa crispata *E. & H.*
	,, microphthalma (not of *Lam.*)	Cyphastræa Danæ *E. & H.*
	,, ocellina	,, ocellina *E. & H.*
720.	,, orion	Orbicella orion *Dana.*
205.	Siderina galaxea	Siderastræa radians *Verrill.*
205.	Astræa (Fissicella) speciosa	Astræa [4] speciosa *Dana.*
	,, ,, uva	Dichocœnia uva *E. & H.*
	,, ,, ananas	Astræa ananas *Lam.*
	,, ,, pandanus	,, pandanus *Dana.*
	,, ,, puteolina	,, puteolina *Dana.*

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
205.	Astræa (Fissicella) pallida	Astræa pallida *Dana.*
	dipsacea	Acanthastræa dipsacea *Verrill.*
	,, ,, porcata (not of. *Esper*)	Astræa Danæ *Verrill.*
	,, ,, flexuosa	Prionastræa flexuosa *Verrill.*
	,, ,, fusco-viridis	,, fusco-viridis *E. & H.*
	,, ,, virens	,, virens *E. & H.*
	,, ,, echinata	Acanthastræa echinata *E. & H.*
	,, ,, fragilis	Astræa fragilis *Dana.*
	,, ,, tenella	Acanthastræa tenella *Verrill.*
	,, ,, magnifica (not of *Ev.*)	Prionastræa spectabilis *Verrill.*
	,, ,, filicosa	Orbicella filicosa *Verrill.*
	,, ,, versipora	Astræa versipora *Lam.*
	,, ,, ,, (var.)	,, Putnami *Verrill.*
	,, ,, denticulata (not of *Lam.*)	,, cellulosa *Verrill.*
	,, ,, pectinata	,, pectinata *Dana.*
	,, ,, deformis	Aplirastræa deformis *E. & H.*
	,, ,, var. dedalina	Cœloria dædalina *Verrill.*
	,, ,, varia	,, spongiosa, var. *E. & H.*
	,, ,, rigida	Isophyllia rigida *Verrill.*
	,, ,, reticularis (not of *Lam.*)	Prionastræa Agassizii *E. & H.*
	,, ,, petrosa	Dichocœnia petrosa *Verrill.*
	,, ,, purpurea	Leptastræa purpurea *Verrill.*
	,, ,, pulchra	,, pulchra *Verrill.*
	,, ,, pentagona	Goniastræa pentagona *Verrill.*
	,, ,, favistella	,, favistella *Verrill.*
	,, ,, var., from Wakes I.	Astræa Pacifica *Verrill.*
	,, ,, eximia	Goniastræa eximia *E. & H.*
	,, ,, sinuosa	Prionastræa sinuosa *Verrill.*
	,, ,, melicerum	,, melicerum *E. & H.*
	,, ,, parvistella	Goniastræa parvistella *E. & H.*
	,, ,, favulus	Prionastræa favulus *Verrill.*
	,, ,, cerium	Goniastræa cerium *E. & H.*
	,, ,, intersepta (not of *Lam.*)	Plesiastræa armata *Verrill.*
	,, ,, abdita	Prionastræa abdita *E. & H.*
	,, ,, tesserifera	,, tesserifera *E. & H.*
	,, ,, robusta	,, robusta *E. & H.*
	,, ,, complanata (?)	,, complanata *E. & H.*
	,, ,, heliopora	Orbicella heliopora *Verrill.*
	,, figured	Prionastræa valida *Verrill.*
	,, ,, Hemprichii	Prionastræa Hemprichii *E. & H.*
	,, ,, halicora	,, halicora *E. & H.*
	,, ,, cyclastra	Astræa cyclastræa *Dana.*
	,, ,, favosa	Prionastræa favosa *E. & H.*
254.	Meandrina dedalea (not of *Ellis*)	Cœloria dædalina, var. *Verrill.*
	,, spongiosa	,, spongiosa *E. & H.*

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
205.	Meandrina labyrinthica	Mæandrina labyrinthiformis *Verrill.*
	,, strigosa	unchanged.
	,, interrupta	,,
	,, rustica	,,
	,, valida	,,
	,, phrygia (not of *Ellis*)	Mæandrina rudis *Verrill.*
	,, gracilis	Leptoria gracilis *E. & H.*
	,, tenuis	,, tenuis *E. & H.*
	,, filograna	Mæandrina clivosa (young) *Verrill.*
	,, cerebriformis	Diploria cerebriformis *E. & H.*
	,, truncata	,, truncata *E. & H.*
	,, mammosa	Mæandrina clivosa *Verrill.*
	,, cylindrus	Dendrogyra cylindrus *Ehr.*
	,, caudex	,, caudex *Ehr.*
266.	Monticularia microcona	Hydnophora microconos *E. & H.*
	,, lobata	,, exesa *E. & H.*
	,, polygonata	,, polygonata *E. & H.*
270.	Phyllastræa tubifex	unchanged.
271.	Merulina ampliata	,,
	,, regalis	,,
	,, speciosa	,,
	,, crispa	,,
	,, folium	Hydnophora Demidoffi *Fischer.*
	,, scabricula	Clavarina scabricula *Verrill.*
	,, laxa	unchanged.
	,, rigida	Hydnophoro rigida *E. & H.*
278.	Echinopora undulata	unchanged.
	,, rosularia	,,
	,, ringens	,,
	,, reflexa	,,
	,, aspera	Trachypora aspera *Verrill.*
	,, horrida	Acanthopora horrida *Verrill.*
289.	Fungia cyclolites	Cycloseris cyclolites *E. &. H.*
	,, tenuis	,, tenuis *Verrill.*
	,, glans	,, glans *Verrill.*
	,, discus	unchanged.
	,, agariciformis	Fungia patella *E. & H.*
	,, var. tenuifolia	,, tenuifolia *Dana* (not *E. & H.*
	,, dentata	unchanged.
	,, echinata (not of *Pallas*)	Fungia Danæ *E. & H.*
	,, var. from Feejees	,, lacera *Verrill.*
	,, repanda	unchanged.
	,, integra	,,
	,, confertifolia	,,
	,, horrida	,,
	,, actiniformis	,,
	,, crassitentaculata	,,
	,, Paumotensis	Lobactis Paumotensis *Verrill.*
	,, dentigera	,, Danæ *Verrill.*
	,, scutaria	Pleuractis scutaria (Ag. MSS.) *Verrill.*
	,, pectinata	Ctenactis echinata (Ag. MSS.) *Verrill.*

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
289.	Fungia Ehrenbergii	Ctenactis Ehrenbergii *Verrill.*
	,, var. gigantea	,, gigantea *Verrill.*
	,, asperata	,, asperata *Verrill.*
	,, Ruppellii	,, echinata *Verrill.*
	,, crassa	,, crassa *Verrill.*
307.	Herpetolithus limacinus	Herpetolitha limax *Esch.*
	,, interruptus	,, ,,
	,, foliosus	,, ,,
	,, stellaris	,, ,,
	,, strictus	unchanged.
	,, crassus	,,
311.	Halomitra pileus (not of *Linn.*)	Halomitra clypeus *Verrill.*
313.	Polyphyllia talpa	Cryptabacia talpina *E. & H.*
	,, leptophylla	,, leptophylla *E. & H.*
	,, sigmoides	,, sigmoides *Verrill.*
	,, pelvis	unchanged.
	,, fungia	
	,, pileiformis	Lithactinia pileiformis *E. & H.*
	,, galeriformis	,, galeriformis *E. & H.*
319.	Zoöpilus echinatus	unchanged.
321.	Pavonia explanulata	Podabacia crustacea *E. & H.*
	,, crispa	Haloseris crispa *E. & H.*
	,, papyracea	Leptoseris papyracea *Verrill.*
	,, elephantotus (not of *Pallas*)	Mycedium elegans *E. & H.*
	,, cactus	unchanged.
	,, prætorta	,,
	,, formosa	,,
	,, venusta	,,
	,, divaricata	,,
	,, boletiformis (not of *Lam.*)	Pavonia Danæ *Verrill.*
	,, frondifera	unchanged.
	,, decussata	,,
	,, lata	,,
	,, crassa	,,
	,, var. loculata	Pavonia loculata *Verrill.*
	,, siderea	Siderastræa siderea *Blainv.*
	,, latistella	unchanged.
	,, clavus	Siderastræa clavus *Verrill.*
335.	Agaricia (Undaria) undata	Undaria[5] undata *Dana.*
	,, ,, rugosa (not of *Lam.*)	,, monticulosa *Verrill.*
	,, ,, speciosa	,, speciosa *Dana.*
	,, ,, levicollis	,, levicollis *Dana.*
	,, ,, planulata	Asteroseris planulata *Verrill.*
	,, (Mycedia) cucullata	Mycedium elephantotus *E. & H.*
	,, ,, purpurea	Agaricia purpurea *Les.*
	,, ,, fragilis	Mycedium fragile *Verrill.*
	,, ,, gibbosa	Agaricia gibbosa *Dana.*
	,, ,, agaricites	,, agaricites *E. & H.*

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
335.	Agaricia (Mycedia) cristata (not of *Lam.*)	Agaricia Danæ *E. & H.*
345.	Psammocora obtusangula	unchanged.
	,, plicata (not of *Lam.*)	Psammocora frondosa *Verrill.*
	,, fossata	unchanged.
	,, columna	,,
	,, exesa	,,
349.	Monomyces anthophyllum	Flabellum anthophyllum *E. & H.*
	,, eburneus	Caryophyllia cyathus *Lam.*
370.	Cyathina cyathus	,, ,,
	,, pezita	,, ,,
	,, Smithii	,, Smithii *Stokes.*
	,, turbinata	,, clavus *Scacchi.*
375.	Desmophyllum dianthus	Desmophyllum crista-galli *E. & H.* (?)
	,, stellaria	unchanged.
376.	Culicia stellata	,,
	,, tenella	,,
	,, truncata	,,
379.	Caryophyllia cespitosa	Cladocora cespitosa *Forbes.*
	,, conferta	,, conferta *E. & H.*
	,, flexuosa	,, stellaria *E. & H.* (?)
	,, arbuscula	,, arbuscula *Edw.*
	,, cornigera	Dendrophyllia cornigera.
	,, anthophyllum	Lophohelia anthophyllites *E. & H.*
	,, solitaria	Astrangia solitaria *Verrill.*
	,, pocillum	Phyllangia pocillum *Verrill.*
	,, dilatata	
385.	Dendrophyllia ramea	unchanged.
	,, micrantha	,,
	,, nigrescens	,,
	,, aurantiaca	
	,, coccinea	Dendrophyllia Danæ *Verrill.*
	,, diaphana	unchanged.
	,, rubeola	
	,, scabrosa	Balanophyllia scabrosa *Verrill.*
391.	Oculina hirtella	Sclerohelia hirtella *E. & H.*
	,, horrescens	Acrohelia horrescens *E. & H.*
	,, prolifera	Lophohelia prolifera *E. & H.*
	,, axillaris	Cyathohelia axillaris *E. & H.*
	,, varicosa	unchanged.
	,, oculata	
	,, pallens	unchanged.
	,, virginea	Lophohelia oculata *Pourt.*
	,, diffusa	unchanged.
399.	Anthophyllum musicale	Galaxea musicalis *Oken.*
	,, fasciculatum	,, fascicularis *Oken* (in part).
	,, astreatum	,, astræata *E. & H.*
	,, cespitosum	,, cespitosa *Verrill.*
	,, hystrix	,, hystrix *Verrill.*
	,, cuspidatum	,, cuspidata *Oken.*

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
399.	Anthophyllum clavus	Galaxea clavus *E. & H.*
404.	Stylina echinulata	unchanged.
406.	Astroitis calicularis	,,
	,, viridis	Goniopora viridis *E. & H.*
409.	Gemmipora palifera	Turbinaria palifera *E. & H.*
	,, peltata	,, peltata *E. & H.*
	,, patula	,, patula *E. & H.*
	,, crater	,, crater *Oken.*
	,, cinerascens	,, cinerascens *Oken.*
	,, frondens	,, frondens *Verrill.*
	,, brassica	,, brassica *E. & H.*
414.	Astræopora pulvinaria (not of *Lam.*)	Astræopora profunda *Verrill.*
	,, punctifera	unchanged.
	,, fungiformis	Turbinaria fungiformis *Verrill.*
	,, stellulata	,, stellulata *E. & H.*
418.	Isaura Hemprichii	unchanged.
	,, Savignii	,,
	,, aster	,,
	,, speciosa	,,
420.	Zoantha Ellisii	Zoanthus Ellisii *Lam.*
	,, sociata	,, sociatus *Les.*
	,, Solandri	,, Solandri *Les.*
	,, dubia	,, dubius *Les.*
	,, Bertholetii	,, Bertholetti *Ehr.*
423.	Palythoa denudata	Mammillifera denudata *Ehr.*
	,, auricula	,, auricula *Les.*
	,, nymyhæa	,, nymphæa *Les*
	,, fuliginosa	,, fuliginosa *Ehr.*
	,, mammillosa	unchanged.
	,, ocellata	,,
	,, glareola	,,
	,, flavo-viridis	,,
	,, argus	,,
	,, cæsia	,,
435.	Madrepora	Madrepora.
	Names of species unchanged except the following :	
	No. 23, corymbosa (not of *Lam.*)	Madrepora convexa (young) *Dana.*
	,, 26, plantaginea (not of *Lam.*)	,, appressa (var.) *Dana.*
	,, 28, acervata	,, plantaginea *Lam.*
	,, 56, secunda	,, nobilis (var.) *Dana.*
	,, 90, deformis (not of *Mich.*)	,, Danæ *Verrill.*
491.	Manopora	Montipora.
	Names of species unchanged, except the following :	
	No. 1, gemmulata	Turbinaria gemmulata *Verrill.*
	,, 6, crista-galli (not of *Ehr.*)	Montipora aspera *Verrill.*
	,, 7, spumosa (not of *Lam.*)	M. hispida (var.) *Dana.*
	,, 8, circumvallata	M. monasteriata *E. & H.*
	,, 9, foliosa (not of *Pallas*)	M. Ehrenbergii *Verrill.*

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
	No. 21, nudiceps	M. crista-galli *E. & H.*
	,, 25, tuberculosa (not of *Lam.*)	M. Danæ *E. & H.*
511.	Alveopora retepora	unchanged.
	,, dedalea (from Red	,,
	,, ,, Sea) (specimen figured)	Alveopora Verrilliana *Dana.*
	,, spongiosa	unchanged.
	,, rubra	Montipora rubra *E. & H.*
	,, fenestrata	unchanged.
	,, viridis	,,
515.	Sideropora digitata	Stylophora digitata *E. & H.*
	,, elongata	,, ,,
	,, pistillata	,, pistillata *Schweigger.*
	,, subdigitata	,, ,,
	,, palmata	,, Danæ *E. & H.*
	,, mordax	,, mordax *Verrill.*
519.	Seriatopora subulata	unchanged.
	,, lineata	,,
	,, hystrix	,,
	,, octoptera	,,
	,, caliendrum	,,
	,, var. gracilis	Seriatopora gracilis *Dana.*
	,, valida	unchanged.
523.	Pocillopora	Pocillipora.
	Names of species unchanged, excepting:	
	No. 3, brevicornis (var. from Sandwich Islands).	Pocillipora cespitosa *Dana.*
	,, 6, favosa (var. from Feejees)	,, Danæ *Verrill.*
	,, ,, (var. from Sandwich Islands)	,, aspera *Verrill.*
	,, 7, verrucosa (var. from Sandwich Islands)	,, nobilis *Verrill.*
	,, 15, plicata (var. from Sandwich Islands)	,, aspera (var. lata) *Verrill.*
540.	Heliopora cœrulea	unchanged.
543.	Millepora alcicornis	,,
	,, moniliformis	Millepora alcicornis (var.) *Linn.*
	,, ramosa	unchanged.
	,, pumila	,,
	,, tortuosa	,,
	,, plicata	,,
	,, complanata	A variety of plicata. (?)
	,, squarrosa	unchanged.
	,, platyphylla	,,
	,, mordax	,,
	,, compressa	,,
	,, clavaria	,,
	,, flexuosa	,,
551.	Porites furcata	,,
	,, recta	Porites furcata (var.) *Lam.*

PAGE	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
551.	Porites divaricata	unchanged.
	,, conferta	,,
	,, nigrescens	,,
	,, var. mucronata	Porites mucronata *Dana.*
	,, palmata	unchanged.
	,, levis	,,
	,, cylindrica	,,
	,, contigua (not of *Esper*)	Synarœa Dana *Verrill.*
	,, astræoides	unchanged.
	,, conglomerata (not of *Lam.*)	Porites lutea *E. & H.*
	,, lobata	unchanged.
	,, fragosa	,,
	,, limosa	,,
	,, favosa	,,
	,, cribripora	,,
	,, informis	Synarœa informis *Verrill.*
	,, erosa	,, erosa *Verrill.*
	,, monticulosa	,, monticulosa *Verrill.*
	,, lichen	unchanged.
	,, reticulosa	,,
	,, arenacea	Porites arenosa *E. & H.*
569.	Goniopora pedunculata	unchanged.
	,, columna	,,
	,, Savignyi	,,
571.	Errina aspera	,,
575.	Antipathes? spiralis	,,
	,, anguina	,,
	,, larix	,,
	,, eupteridea	,,
	,, pectinata	Hyalopathes pectinata *E. & H.*
	,, myriophylla	unchanged.
	,, subpinnata	,,
	,, reticulata	,,
	,, flabellum	,,
	,, ericoides	,,
	,, mimosella	,,
	,, pinnatifida	,,
	,, cupressus	,,
	,, paniculata	,,
	,, pennacea	,,
	,, scoparia	,,
	,, fœniculum	,,
	,, corticata	Hyalopathes corticata *E. & H.*
	,, lacerata	unchanged.
	,, pyramidata	Hyalopathes pyramidata *E. & H.*
	,, Boscii	unchanged.
	,, alopecuroides	,,
	,, arborea	,,
	,, dichotoma	,,
	,, glaberrima	Leiopathes glaberrima *E. & H.*
	,, compressa	,, compressa *E. & H.*

[1] The genus, *Mussa*, as here restricted, includes both *Mussa* and *Symphyllia* of Milne-Edwards and Haime,—different specimens of the same species sometimes differing in the same way, and to the same extent, as do these two so-called genera. The only difference given, is dependent upon the mode of growth.

[2] It is probable that this, and some of those following it, are only varieties of one species.

[3] The name *Orbicella* is now restricted to the genus of which *O. annularis* and *O. cavernosa* are types. This group is equivalent to *Heliastræa* of Edwards and Haime, of more recent date.

[4] The genus, *Astræa*, is here restricted to the group of which *A. rotulosa* is the type. This was the original type named by Lamarck, in 1801, when the genus *Astræa* was first established. The genus, thus limited, is equivalent to *Favia* of Oken, 1815.

[5] The genus, *Undaria*, is equivalent to *Pachyseris* Edwards and Haime, of later date.

[6] *Cœnopsammia* is recombined with *Dendrophyllia*, because in certain species part of the corallets have the structure of the former genus, and others that of the latter, even in the same specimen. The only distinction made is that the former genus has a smaller number of lamellæ,—a character that is by itself seldom of generic value.

[7] The genus, *Antipathes*, as here adopted, includes *Cirrhipathes*, *Arachnopathes*, and *Rhipidopathes* of Edwards and Haime. Those divisions were based only upon the modes of growth and branching, which are quite insufficient for establishing genera among Polyps.

V. LIST OF WORKS AND MEMOIRS REFERRED TO, AND OF ABBREVIATIONS.

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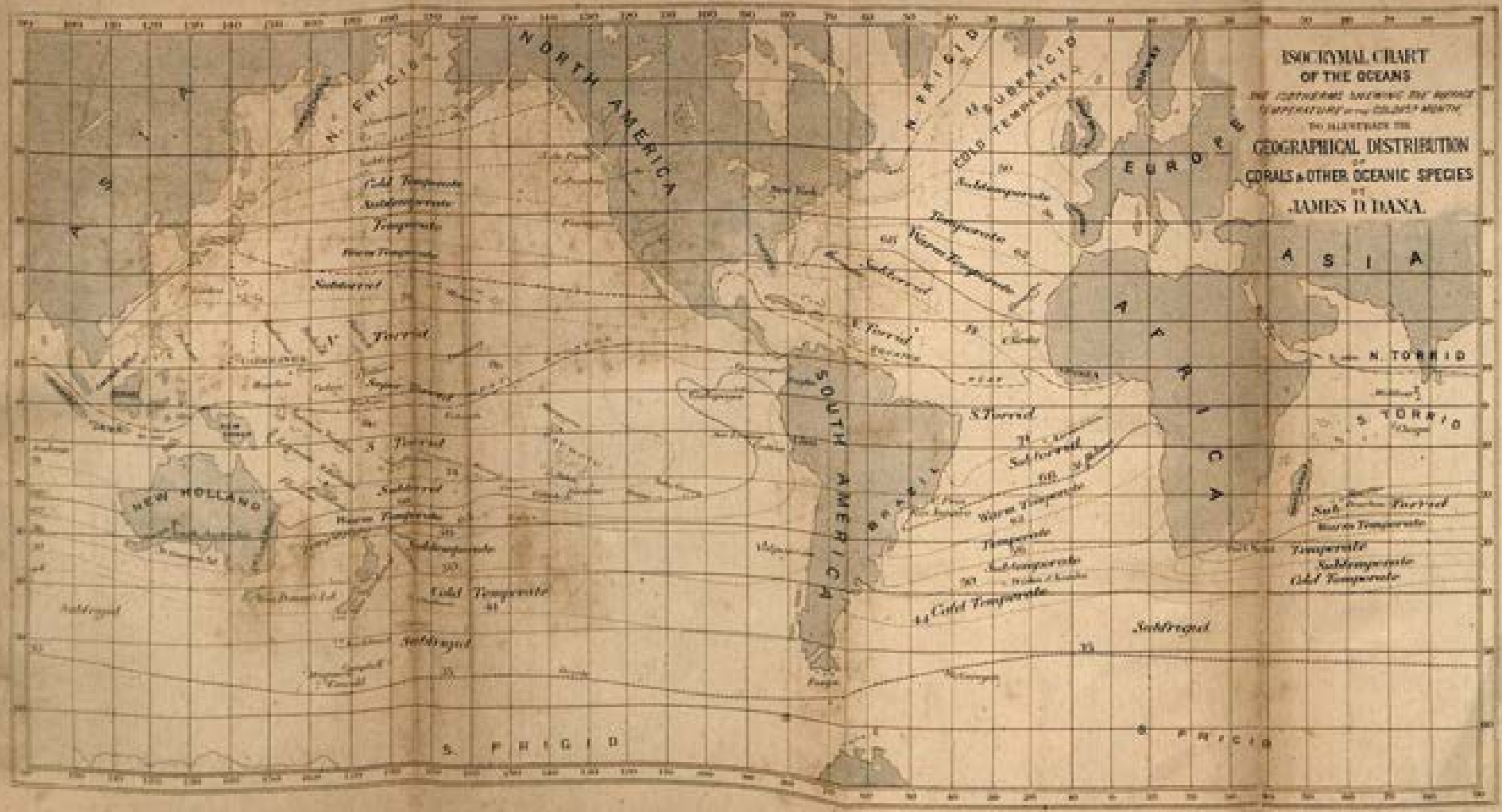
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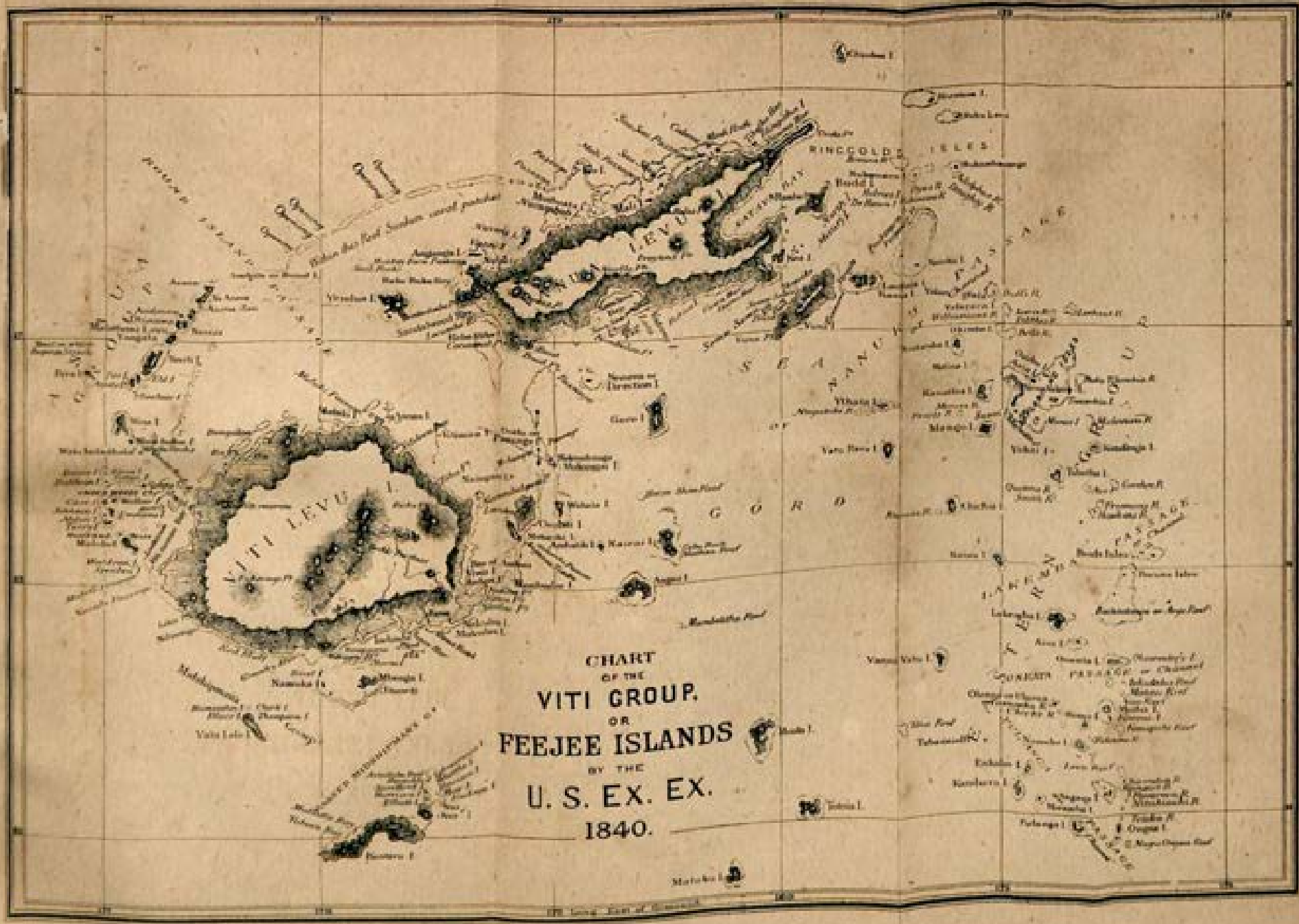
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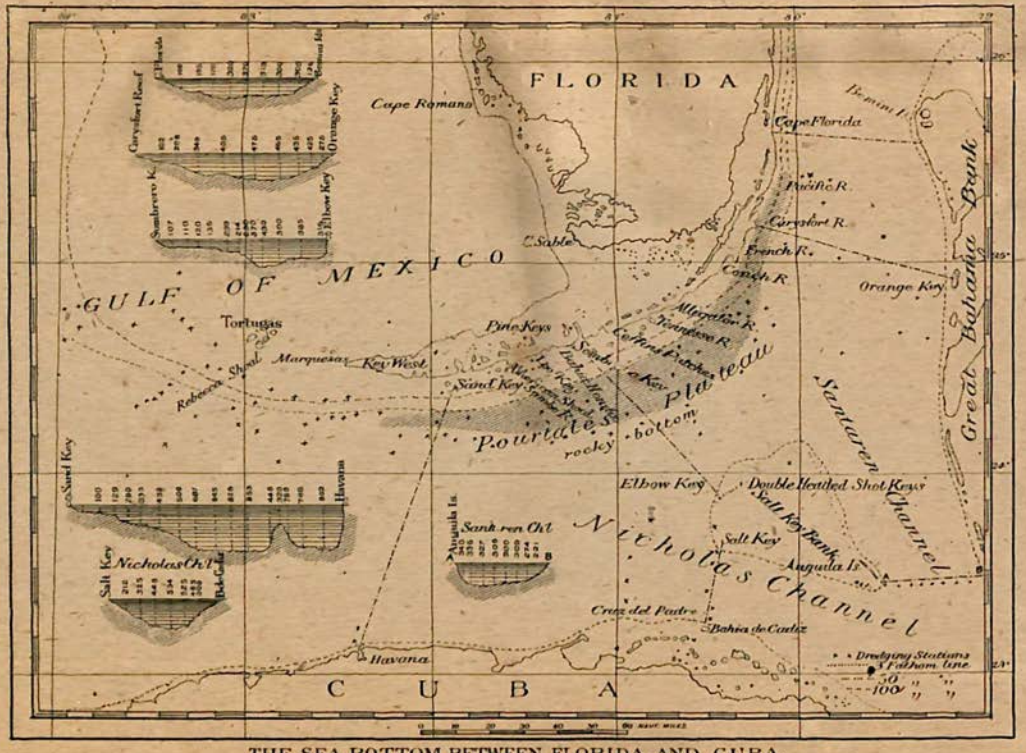
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ISOCRYMAL CHART
OF THE OCEANS
GEOGRAPHICAL DISTRIBUTION
OF
CORALS & OTHER OCEANIC SPECIES
BY
JAMES D DANA.
N. FRIGID
N. TORRID
S. TORRID
S. FRIGID
NORTH AMERICA
SOUTH AMERICA
EUROPE
ASIA
AFRICA
NEW HOLLAND
Cold Temperate
Subtemperate
Temperate
Warm Temperate
Subtorrid
Torrid
Subfrigid


CHART
OF THE
VITI GROUP,
OR
FEEJEE ISLANDS
BY THE
U. S. EX. EX.
1840.



THE SEA BOTTOM BETWEEN FLORIDA AND CUBA.


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